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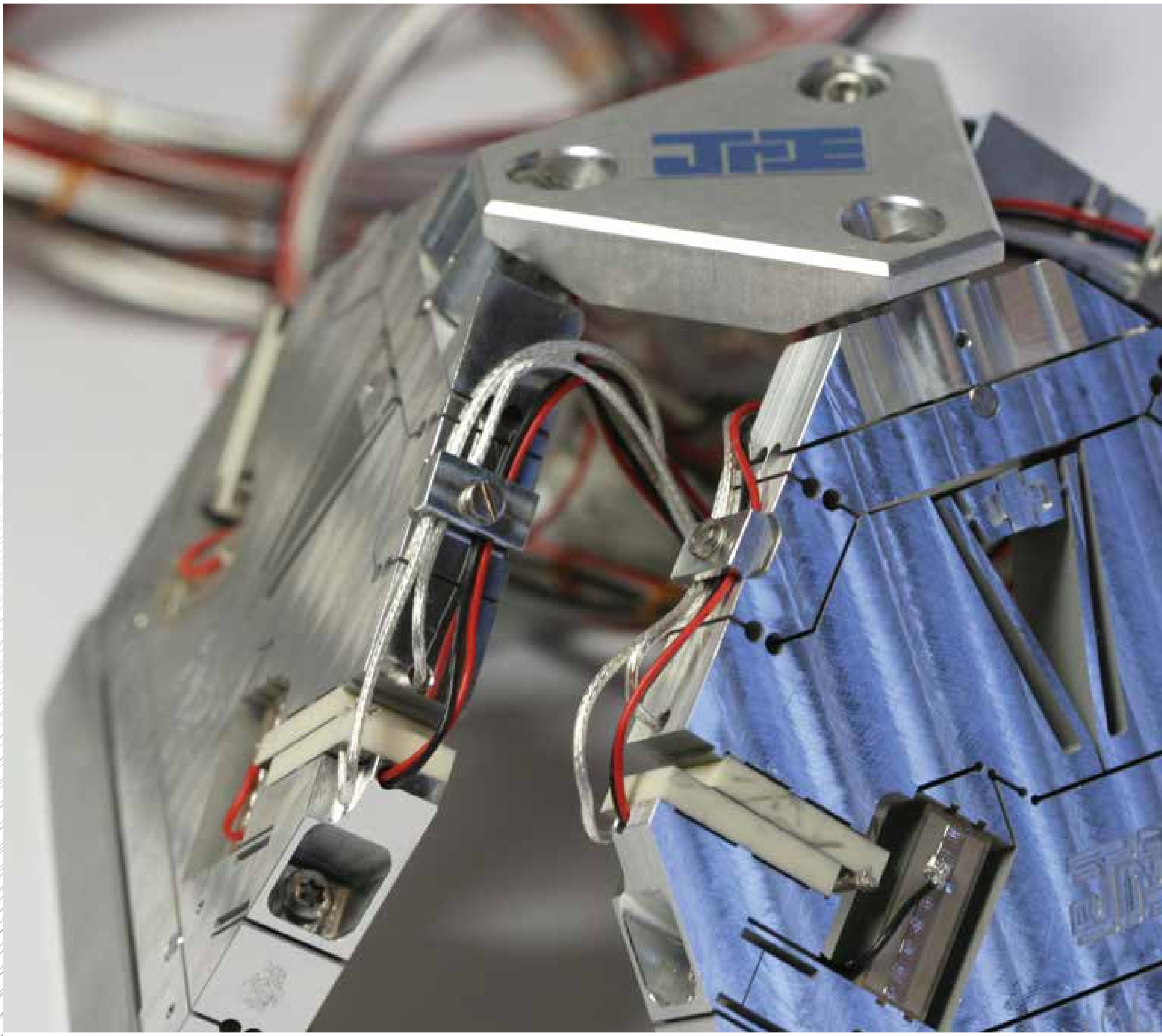

- THEME: **CONTAMINATION/VACUUM**
- **EDM** ELECTRONICALLY REVITALISED
- **WIM VAN DER HOEK** AWARD NOMINEES
- **PRECISION FAIR 2017** PREVIEW

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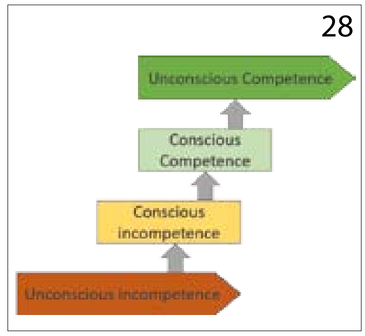

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EDITORIAL

NO CLEANROOMS, NO INTERNET OF THINGS

What we think nowadays is quite normal, such as the use of all kinds of electronic appliances, could never have been achieved without cleanroom technology. Since the invention of HEPA filtration and unidirectional flow, the world has totally changed. We could never have succeeded in putting a man on the moon without cleanrooms. Suddenly, it was possible to work with really clean environments and this accelerated the micro-electronics/semiconductor industry beyond everyone's dreams. Without cleanrooms no computers, no driving cars, ..., the list is endless.

In the Netherlands, we have made a fortune with all kinds of machines used in the micro-electronics industry. Luckily, we also have lots of small start-ups here to keep up with the speed of development. We are therefore still a big player in the machinery business, but we have to work everyday on contamination control. Today you can be king and tomorrow just a small player; we all know what happened to Nokia: the world leader in mobile phones that was blown away by smartphones.

The development of clean environments started with ballroom-type rooms and led us to clean machines. The work coat changed to coveralls and this will only keep on progressing, towards smart cleanrooms with adaptive control. And the drive for miniaturisation continues. Looking into the future, we will have lots of new products and you can be sure that these all need controlled environments to produce. Just think of the internet of things, robotics, self-driving systems, artificial intelligence, biotechnology, nanotechnology, etc.

The future will be bio-cleanrooms: the micro-electronics industry interfacing with the pharmaceutical industry works very well. Digital printing is on the rise, the exchange of parts of our body with artificial parts, and robots will be as normal as pets. Biotechnology will use nanobots; nanoparticles adhering to proteins for drug delivery to the right place in our bodies, so that the drug will not affect the good cells and the problem will naturally disappear.

As the costs of controlled environments are also exploding, we have to look for more cost-effective ways of working. Not only hands-on people are looking into this, the ISO working groups are doing so as well; they are changing the standards and considering how to align engineering. No more engineering based only on experience. Now the ISO 14644 standard with all its parts from 1 to 16 will oversee this by way of risk assessment. Determine your risks and then engineer accordingly, avoiding overkill in the dimensioning of your controlled environment. Think about how to establish control, which gowning discipline (gloves, mouth caps, etc.) you need, and then demonstrate control.

The cleaning of the cleanroom is a very important part of establishing control, and cleaning of the products used in subassemblies will be a major issue. Machine builders nowadays must control contamination levels, as contamination has a negative influence on the performance of their production machines. The supply chain of the OEM machine builders in the Netherlands must deliver their products with a high standard of cleanliness. The types of contamination, such as particles, micro-organisms, chemicals and nanoparticles, may vary, but they all directly or indirectly influence the product. Demonstrating control also receives a lot of attention regarding how to achieve this. Increasing demand for training is a logical consequence, as people's behaviour is a major source of contamination.

These are major challenges to maintain the leading Dutch position in the international markets.

Philip van Beek
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CONTAMINATION CHALLENGES, SOLUTIONS AND STANDARDS

AUTHOR'S NOTE

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Every year, new contamination-sensitive products (sensors, actuators, displays, smart devices, medical devices, etc.) and manufacturing tools are developed. As the vulnerable surface area of many of these products is increasing, so is the growing need for clean manufacturing methods. To meet future challenges, more dedicated contamination control solutions are also required. This article provides an overview of contamination challenges, solutions and standards.

KOOS AGRICOLA

Introduction

Cleanroom technology and contamination control are applied to keep the surfaces of products or parts sufficiently clean. In order to select the proper methods for keeping a product or a specific part of a product clean, one needs to understand the functional requirements of the (oftentimes complex) product. One should know what type of contaminants and how much contaminant can harm the product's performance and quality (Figure 1). It is important that the product or parts are cleaned to a cleanliness level higher than the required cleanliness of the final product. The total acceptable contamination during processing can be determined from the difference between these levels.

1 *In clean environments, people are a main source of contamination.*

This information can be used to select the proper contamination control solution for critical locations in the manufacturing process of the product.

The requirements for critical manufacturing locations can be deduced using a risk assessment. The cleanliness requirements are the input for the selection of contamination control solutions: when the proper potential solution is selected, the required control can be established and verified. Once the processes are executed, the air and surface cleanliness should be monitored to demonstrate that the manufacturing processes are under control.

Product cleanliness

To express the cleanliness of a product, the concentration of contaminants on the outer surface is determined. Contaminants can be particles and/or chemicals. In this article, microbiological contamination and nano-size particles will not be considered. However, the general approach for these contaminants will be similar [1].

For particles, the number concentration of particles larger than one or more specific sizes is generally used. For chemicals, it is the mass concentration per type of chemical that is commonly used. There are various general international standards, branch-related standards and guidelines that can be used to express surface cleanliness. Once the specific concentrations are known, the values for each standard can be calculated relatively easily, using ISO 14644-9:2012 and ISO 14644-10:2013. ISO 14644, developed by the ISO Technical Committee 209 for Cleanrooms and associated controlled environments [2], comprises a total of fourteen standards [3]; see Table 1.

Table 1. The set of standards under ISO 14664 – Cleanrooms and associated controlled environments.

1 (2015)	Classification of air cleanliness by particle concentration
2 (2015)	Monitoring to provide evidence of cleanroom performance related to air cleanliness by particle concentration
3 (2005)	Test methods
4 (2001)	Design, construction and start-up
5 (2004)	Operations
7 (2004)	Separative devices (clean air hoods, gloveboxes, isolators and mini-environments)
8 (2013)	Classification of air cleanliness by chemical concentration (ACC)
9 (2012)	Classification of surface cleanliness by particle concentration
10 (2013)	Classification of surface cleanliness by chemical concentration
12 (*)	Specifications for monitoring air cleanliness by nanoscale particle concentration
13 (2017)	Cleaning of surfaces to achieve defined levels of cleanliness in terms of particle and chemical classifications
14 (2016)	Assessment of suitability for use of equipment by airborne particle concentration
15 (*)	Assessment of suitability for use of equipment and materials by airborne chemical concentration
16 (*)	Code of practice for improving energy efficiency in cleanrooms and clean air devices

** Under development*

The starting point is the product surface cleanliness by particles (SCP) or chemical concentration (SCC) after cleaning:

- Number of particles N_D (with size ≥ D μm) per m².
  ISO SCP class is $\log_{10}$ ($N_D \cdot D$), where D is the largest size of the particle expressed in μm.
  For example, 1 particle ≥ 20 μm per cm² or 10,000 particles ≥ 20 μm per m² is then ISO SCP $\log_{10}$ 20·10,000 = ISO SCP 5.3.
- Mass m in grams, per m².
  ISO SCC class is $\log_{10} m$, which is a negative number.
  For example, 1 ng per dm² or 10^{-7} grams hydrocarbons per m² is then ISO SCC –7 hydrocarbon.

The particle size of interest is $D \leq D_{critical}$. Sometimes more than one critical particle size is specified. In ISO 14644-9, the relation $N_{D1} \cdot D_1 = N_{D2} \cdot D_2$ is used. In other standards, different levels for different particle size ranges are used.

Contamination mechanisms

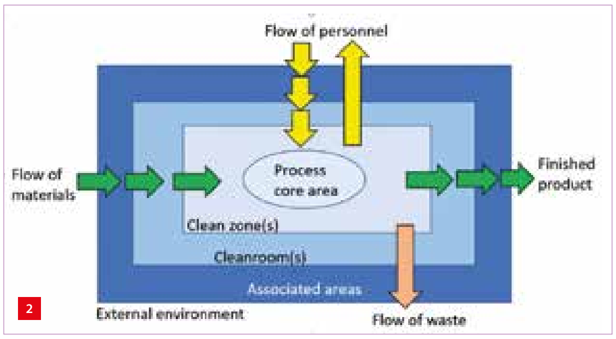
A clean surface can be contaminated by deposition or by contact transfer. Particles (larger than a few microns) in air fall by gravitation, while being carried by air flow. Turbulences transfer momentum towards these particles. When a pocket of air passes a surface, particles can be deposited onto that surface if their mass is high enough. Small particles and particles with a high area-volume ratio will stay airborne. These particles can be removed with an air flow. Particle deposition measurements show that particles larger than 20-30 μm are not removed from a room effectively by air flow.

The deposition of particles onto a surface depends on their concentration in the air and their deposition velocity. In addition, deposition can be influenced by electrostatic forces near an electrostatically charged surface. If the product is in vacuum, particles can only be deposited during pumping and venting, as particles are transported by an air flow.
Particles can also be transferred via contact with another surface. This transfer is determined by the difference in surface cleanliness, the transfer coefficient (which depends on the contact conditions), the contact area and the number of contacts. The transfer efficiency is somewhere between 2% and 20%, being low on smooth, hard surfaces and high on flexible surfaces. Contact surfaces can be contaminated by particle deposition and by contact with dirty surfaces, often involving long exposure times. Regular cleaning, controlling the particle deposition rate and avoiding the unnecessary exposure of tools will help to limit surface contamination. If the product is in a liquid, particles can also be deposited depending on the concentration and liquid flow around the product.

Unwanted chemical substances can condense or adsorb on surfaces. This deposition depends on the concentration, the type of chemical, the surface condition and the temperature. When in contact with surfaces that are chemically unclean, the chemical substances involved can be transferred onto the clean product surface.

Contamination control solutions

To limit surface contamination, the concentration of airborne contaminants of interest should be sufficiently low and under control. The principles of contamination control solutions are isolation (box in box in box), limitation of the generation of contaminants and prevention of the transport of contaminants into a controlled environment.
A controlled environment is cleaned by flushing it with filtered air and by regular cleaning of all surfaces. A large controlled environment in which people can work is a



2 *Schematic overview of a cleanroom and clean zone.*

cleanroom (see Figure 2). The supplied air is filtered with HEPA or ULPA filters [4] that are classified with respect to the filter efficiency of the most penetrating particle size (MPPS).

The most commonly used ventilation system is dilution with non-unidirectional air flow. In the most critical cleanrooms or clean zones, displacement by unidirectional air flow is applied. The performance of cleanrooms is classified by the concentration of airborne particles (≥ 0.1 to 5 μm) per m^3 in three states of occupancy: 'as built', 'at rest' and 'operational'.

According to ISO 14644-1:2015, a cleanroom can be classified for one particle size. At all sample locations, the measured concentration must be within the class limit. The minimum number of sample locations is determined by the area of a uniform cleanroom. The standard provides a table with sample locations per room area. The concentration limit is determined by $10^{\text{ISO Class}} / (10 \cdot d)^{2.08}$, where d is the equivalent particle size between 0.1 and 5 μm.

When the resulting concentration is too low (< 10 particles), it cannot be used for classification for statistical reasons. In respect to particles ≥ 5 μm, the problem of particles getting stuck in the measurement system sets this limit at 100 particles ≥ 5 μm. So, if a cleanroom of 100 m^2 should be classified during operation as ISO 6.5 for particles ≥ 1 μm, the limit is $10^{6.5} / 10^{2.08} = 10^{4.42} =$ 26,300 particles ≥ 1 μm per m^3.

If the cleanroom fulfils this condition, this is expressed as: "ISO Class 6.5; operational, 1 μm". Of course, it is possible to classify for more than one particle size. Be aware that if somebody claims to have an ISO Class 6 cleanroom, this information is not complete. What was the occupancy state, for which particle size(s) was it classified, and was the classification procedure according to ISO 14644-1:2015 (or 1999) followed?

If air cleanliness is measured at a critical location, the result should be expressed as a concentration and not as a class. So a measurement of 2,500 particles ≥ 0.5 μm per m^3 may not be expressed as ISO Class 5. The monitoring of the air cleanliness in critical locations is described in ISO 14644-2:2015.

For some applications, the air cleanliness with respect to chemicals (airborne molecular contamination) is important. This is described in ISO 14644-8:2013. Air cleanliness limits for chemical concentration can only be applied at critical locations, since there is no classification procedure for a cleanroom. Cleanliness levels can be achieved by avoiding substances that generate unwanted chemicals and by chemical filtration of the air.

To limit surface contamination by contact transfer, potential contact surfaces such as work benches, tools and equipment should be cleaned regularly to keep the surface cleanliness within acceptable limits (ISO 14644-9:2012 for particles and ISO 14644-10:2013 for chemicals). These surfaces are contaminated by deposition, the most important source for which is the deposition of macro-particles. The Particle Deposition Rate (PDR) is determined by the concentration of the macro-particles in the air and their deposition velocity; see VCCN guideline 9 [5]. The deposition velocity increases with particle size (to be more precise, with particle mass and shape).

The PDR of larger particles is determined by the way the cleanroom is used, or in other words, by the quality of the operational procedures. These include garment use, entrance and exit procedures, and cleaning. Cleaning of large surfaces is executed by professional cleanroom cleaners and cleaning of all working surfaces such as tools is done by the operators. Good cleaning can only be achieved by proper training, cleaning methods and cleaning programmes, according to ISO 14644-5:2004.

It is important to realise that particle deposition builds up on unclean surfaces, which act as a contamination source in the neighbourhood of turbulent air flows and in contact with clean surfaces. The deposition of particles < 5 μm is an extremely low fraction of the airborne concentration and therefore, in many cases, the deposition of macro-particles is the real threat for product quality.

A cleanroom is expensive and consumes a lot of energy, so it is important to look for alternative contamination control solutions. Storing a product in a clean box is a very effective way of keeping the product clean, while keeping people away from the product will prevent contact with the most important particle source and reduce contamination.

By using unidirectional (laminar) flow cabinets, glove boxes and mini-environments, people can be kept away from vulnerable products. With these tools, it should be possible to do without a cleanroom, but one should be aware that during interventions the cleanliness of the surrounding environment is important and therefore a lower-classified cleanroom can be selected to control contamination of the separative device by the background; see ISO 14644-7.

Risk assessment

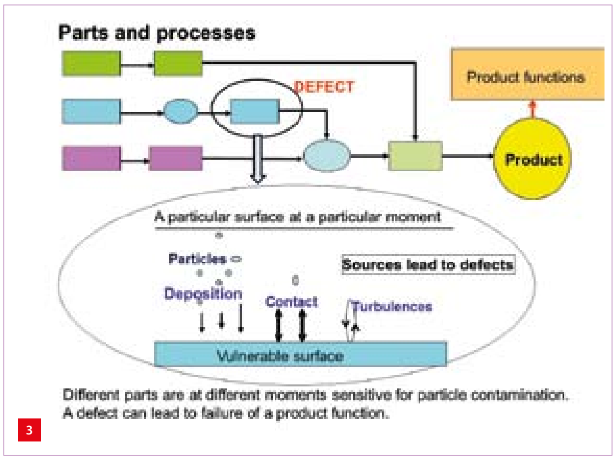
A risk assessment starts with a description of the product's functions and the potential harm of contamination. The first step of a Failure Mode and Effect Analysis (FMEA) serves to make a list of potential product failure or loss of quality. From this list, the vulnerable surfaces can be determined.

For the vulnerable surface, the maximum allowable contamination of particles and/or chemicals should be determined. One should realise that the lower that these maximum quantities are set, the more difficult it is to reach them. Further, the starting point of a vulnerable surface is always the surface cleanliness level after the last cleaning. From the initial surface cleanliness and the accepted final surface cleanliness, the latitude during manufacturing can be determined; the latitude is the working space in terms of cleanliness parameters. The next step is to analyse the manufacturing process and determine where each critical part surface is exposed to contamination by deposition and/or contact transfer (see Figure 3).

At each critical location, the latitude or a part of the latitude can be used to determine air cleanliness, surface cleanliness and deposition rate limits. There are no real formulas to set these limits, but it is possible to make realistic estimates to start an iterative analysis. Determination of the cleanliness levels that can be realised is required to optimise the levels to be set. The set levels can be reached by clean operational procedures, cleanroom conditions and separative devices.

From the risk assessment, the requirements for air cleanliness of particles from 0.1 up to 5 µm and particle deposition rate levels (PDRLs) for particles from 5 to 500 µm at critical location can be derived. The air cleanliness determines the requirements for the cleanroom class(es) of the required cleanroom or clean zones. The particle deposition rate (PDR) level for the smaller particles is determined by the air cleanliness of particles ≥ 5 µm, but for particles ≥ 25 µm, the impact of the cleanroom installation reduces and the impact of operational procedures increases. The PDR in combination with the cleaning programme determines the surface cleanliness of all surfaces in the cleanroom or clean zone.

A calculation example (see the box below) demonstrates steps in the determination of cleanliness levels.



3 *Schematic overview of a manufacturing process highlighting the analysis of a contamination-critical step where defects may occur.*

Calculation example

Take a product surface with an area of 20 cm². This product is most vulnerable for particles ≥ 50 µm, so these are not acceptable. One particle of 25 µm is acceptable and no clusters of particles ≥ 10 µm are acceptable. As a starting point, the requirement for the 'killer particles' is set at 0.2 particles ≥ 50 µm per product.
The requirement for the smaller particles is set as 10 particles ≥ 10 µm per product. These requirements are listed in Table 2. For the three particle sizes, the acceptable final number of particles per product is recalculated into a surface particle concentration and ISO SCP class.

Further, the initial cleanliness level that is achieved after cleaning is given in cleanliness class and 'on product' value. The difference with the acceptable final number of particles is the latitude per particle size. The contamination control solution should keep the contamination within this latitude.

Table 2. Calculation of surface cleanliness latitude with respect to particles (product area 20 cm²; initial cleanlines ISO SCP 3).

Particle size *D* (µm)	Acceptable number of particles on product	Final acceptable concentration (m^{-2})	Surface cleanliness level (m^{-1})	Final SCP class	Initial SCP class	Initial number of particles on product	Latitude per product
10	10	5.000	50.000	4.7	4.0	2.0	8.0
25	1	500	12.500	4.1	3.5	0.3	0.7
50	0.2	100	5.000	3.7	3.0	0.04	0.2

Table 3. Calculation of particle deposition rate and cleaning frequency of contact surface (tool).

		90% deposition			10% contact transfer		
Particle size D (µm)	**Latitude per product**	**Latitude per product**	**PDR_D ($dm^{-2}\cdot hr^{-1}$)**	**PDRL ($dm^{-2}\cdot hr^{-1}$)**	**Latitude per product**	**Max. concentration N_D (cm^{-2})**	**Max. $t_{exposure}$ (hr)**
10	8.0	6.4	64.0	640	1.6	5.3	8.3
25	0.7	0.6	6.0	149	0.1	0.5	8.3
50	0.2	0.1	1.3	64	0.03	0.11	8.2

$PDR_D = N_D / (A \cdot t_{exposure})$ PDRL = $PDR_D \cdot D$
Time of exposure $t_{exposure}$ = 30 minutes
Contact surface $A_{contact}$ = 1.5 cm^2

Number of particles transferred by contact = $n \cdot e \cdot N_D \cdot A_{contact}$
Number of contacts n = 2 and transfer efficiency e = 0.1 (= 10%)
Max. $t_{exposure} = \Delta N_D / (PDR_D \cdot A_{contact})$

The latitude is used to determine the requirements for the contamination control solution. For the observed process, the latitude is divided into 90% particle deposition and 10% contact transfer with a tool with contact area 1.5 cm^2. This is elaborated in Table 3 (using cm^2 and dm^2 units).

The number of particles that is deposited on a product, N_D, is determined by the PDR_D for particles ≥ D µm per dm^2 per hour, the product area A and the time of exposure $t_{exposure}$ in hours:

$$N_D = PDR_D \cdot A \cdot t_{exposure} \quad (1)$$

So the required Particle Deposition Rate Level PDRL = $D \cdot PDR_D = D \cdot N_D / (A \cdot t_{exposure})$. The lowest required level (PDRL is 64) is found for the larger particles. This PDRL can only be kept low by having very good operational procedures. The PDRL for particles that stay airborne for longer is much higher (640). Particles ≥ 25 µm can be removed partially by the cleanroom installation, but operational procedures are much more important.

In the second part of Table 3, the impact of contact transfer is calculated. The number of particles that can be transferred by contact is determined by the number of contacts n, the transfer efficiency e, the contact area $A_{contact}$ and its surface cleanliness SC_D:

$$N_{D,\ contact\ transfer} = n \cdot e \cdot A_{contact} \cdot SC_D \quad (2)$$

The surface cleanliness is determined by the initial surface cleanliness (ISO SCP 3 in this example) plus the contamination during exposure. This means that the tool slowly becomes dirtier and needs to be cleaned when the particle concentration on the contact surface is too high. With this input, the maximum exposure time until the next cleaning can be calculated. In this example, an operational time of eight hours is calculated. There is no deposition of macro-particles in a cleanroom at rest.

The contamination control of particles ≥ 10 µm depends on the cleanroom installation and the number of changes in the air. There is an empirical relation between PDR_5 (per m$^2\cdot$hr) and the airborne concentration C_5 of particles ≥ 5 µm per m^3:

$$PDR_5 = 81.2 \cdot C_5^{0.773} \quad (3)$$

In a cleanroom, the particle deposition rate for particles ≥ 10 µm is proportional to the PDR for particles ≥ 25 µm. The Particle Deposition Rate Level used in a cleanroom is the maximum $D \cdot PDR_D$.

From Table 2 the requirement of the contamination solution, a PDRL of 150 per dm$^2\cdot$hr, or 15,000 per m$^2\cdot$hr, is selected:

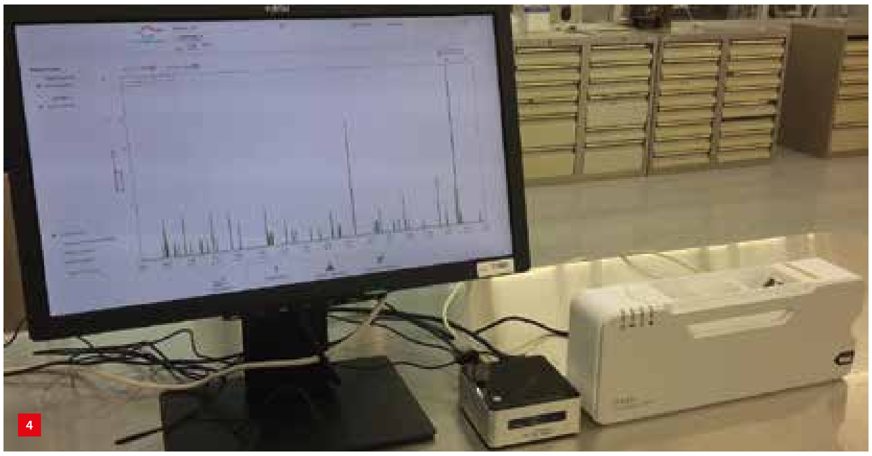
$$PDRL = 5 \cdot PDR_5 \quad (4)$$

From Equations 3 and 4, the concentration of airborne particles ≥ 5 µm per m^3 can be determined:

$$C_5 = (PDR_5 / 81.2)^{1/0.773} = (PDR_5 / 81.2)^{1.29} \quad (5)$$

PDRL is set at 15,000 per m$^2\cdot$hr. Then PDR_5 = 3,000 per m$^2\cdot$hr. This leads to a particle concentration C_5 = 106 particles ≥ 5 µm per m^3. The nearest cleanroom class limit is ISO class 6, which is 290 particles ≥ 5 µm per m^3 (operational).

From experience, a PDRL of 150 per dm$^2\cdot$hr for large particles, which are not removed by the cleanroom installation, can be achieved by full-cover garments, no less than 20 m^2 per person, cleaning all goods that come into the cleanroom and cleaning all surfaces with an effective cleanroom cleaning method each eight operational hours.



4 *The APMON advanced deposition monitoring system from Technology of Sense.*

Measurement methods

Table 4 gives an overview of measurement methods. As an example, air cleanliness with respect to particle concentration can be measured using the APMON (Figure 4) of Technology of Sense [6], which employs inclined glass plates that collect particles and measures the collected particles using a holographic imaging technique.

When determining the requirements for a clean facility, it is important to select the measurement methods that will be used for verification and monitoring. Ideally, a monitoring plan is developed before construction or at least before start-up.

Establishing control

To establish control in a clean controlled environment, one can establish a cleanroom, clean zone or a combination thereof. ISO 14644-4 describes the subjects and parameters that need to be considered when designing and constructing a cleanroom. A revised ISO 14644-4 standard will be issued within two years that will prescribe the minimal set of requirements as a starting point for the establishment of a controlled environment. Cleanroom classification is based on air cleanliness with respect to particles. Chemical cleanliness and surface cleanliness are cleanliness attributes that can only be used at critical locations or in clean zones, but they cannot be used to classify a cleanroom.

To achieve a certain air cleanliness level with respect to chemical cleanliness, the selection of construction materials is important. No materials emitting the forbidden chemicals should be used. For example, no silicone sealant can be used in a cleanroom for coating products.

When designing a cleanroom, it is important to obtain an accurate estimate of the contamination sources (number of people and equipment), since this determines the amount of cleanroom air. In many cleanrooms, the amount of air is too high; this costs a lot of energy. Guidance on energy management will be given in the new ISO 14644-16.

When the clean facility is completed, it should be verified against the required cleanliness attributes. The cleanroom classification can be verified for the 'as-built' and after the equipment is installed for the 'at rest' situation. When the pilot operations are executed, the 'operational' occupancy state can be verified. Relevant people should be trained in how to operate and use the controlled environment. Then the operations can be started.

Demonstrating control

After start-up, the clean facility will be used for regular operation. To demonstrate one is in control, the air cleanliness, particle deposition rate and surface cleanliness should be monitored according to the monitoring plan (see ISO 14644-2:2015). Depending on the results, the measurement frequency can be adapted in the monitoring plan. If the levels of the required cleanliness attributes during an operation drop to action or alert levels, action has to be taken to improve these cleanliness levels again. In

Table 4. Measurement methods for various contamination types.

Contamination type	Measurement method	ISO
Air cleanliness with respect to particle concentration	Measurement is based on data acquired with a light-scattering airborne particle counter. Particle deposition rate is determined by measuring the surface cleanliness of a witness plate before and after exposure. In a real-time particle deposition monitor, a sensor is used to count the change of surface cleanliness on the sensor for every period of five or more minutes.	14644-1
Chemical contamination	This can be measured directly with a spectroscopic instrument, but in most cases the air is sampled in a sorption tube that can be analysed in various ways, mostly by gas chromatography.	14644-8
Surface cleanliness	This is measured directly with a microscopic method or with optical measurement equipment that is developed for this purpose. Surfaces with complicated shapes can be measured indirectly by carrying out a reference cleaning and then measuring the released particles in the cleaning liquid.	14644-9
Chemical contamination on a surface	This can be measured directly on a small surface, but in most cases the surface is cleaned with a solvent and the non-volatile residues are measured using chemical analysis methods.	14644-10

most cases, the operational procedures should be improved. The methods and frequency of cleaning for garments, cleanroom surfaces, tools and equipment are most important. Then the garment changing procedure, the transfer of goods into the room and the working methods should be considered. Unnecessary surfaces such as unused furniture or equipment should be removed as they become particle sources when not cleaned frequently.

Process equipment

Regarding cleanliness, equipment should be treated in a similar way as the clean facility. Moving parts will generate particles and air flow will transport these particles. An approach to quantify this is described in ISO 14644-14. Materials used in equipment can emit unwanted chemicals. The way these can be measured is described in ISO 14644-15.

In a vacuum system, there is a high risk of particle contamination during pumping and venting. During pumping, turbulent airflows will pick up particles from surfaces that can then be deposited on the vulnerable product surface. It is important to control the pumping speed in such a way that no turbulence can occur. This could be done using mass-flow controllers or by pumping through different orifices that are opened step-by-step when it is safe to increase the pumping speed. Venting will also cause turbulence, which can be prevented in a similar way to pumping down. Preferably an inert gas like nitrogen is used to vent in order to avoid condensation or unwanted chemical reactions on the product surface.

Conclusion

A new way of thinking is developing in the world of contamination control and within five years a new approach will be incorporated in the new ISO standards. When developing a manufacturing process for a new product, the first step is a risk assessment. Then the requirements thus determined are used to find the optimal contamination control solutions, ranging from a local solution, like a product container or mini-environment, to a controlled clean environment.

People are the main source of particles in cleanrooms, so the way personnel will enter and work should be considered before drawing up any design. The cleaning programme should be considered right from the beginning. The way the contaminants of interest will be measured should be decided before or at least during the design process. Once the contamination control solution has been established, a monitoring programme should be implemented to demonstrate that one is in control or when corrective actions need to be taken.

The applied process equipment needs a similar approach.

REFERENCES AND NOTES

[1] Micro-organisms can be associated with macro-particles (> 5 μm). Nanoparticles will not pass HEPA filters and can be generated by processes during operation.
[2] *www.iso.org/committee/54874.html*
[3] ISO 14644: Cleanrooms and associated controlled environments; *www.iso.org/ics/13.040.35/x/*
[4] HEPA: High Efficiency Particulate Air (H13 and H14); and ULPA: Ultra Low Penetration Air (U15-U17). 1X stands for 99.9..5% efficiency for the MPPS (somewhere between 0.1 and 0.3 μm), where X is the number of 9's.
[5] *www.vccn.nl/publicaties/vccn-richtlijnen/vccn-rl-9-deeltjesdepositie*
[6] *www.technologyofsense.com*

International Symposium on Contamination Control 2018

In 2018, VCCN (the Dutch Society for Contamination Control) will host the International Symposium on Contamination Control, organised by the ICCCS (International Confederation of Contamination Control Societies). The event will be held in The Hague, the Netherlands, from 23 to 26 September 2018. The symposium's theme is "the world behind contamination control" and will cover such areas as Health Care, Life Sciences, Micro-Nano Electronics, Photonics, Micro Assembly, Food and Space.

The symposium is intended both for people who are new to the field of contamination control and for people who are experienced. The call for papers is open until 15 December 2017.

A total of six workshops will be presented:
- Cleanroom behaviour
- Cleaning
- Monitoring
- Particle deposition monitoring
- Commissioning and Verification
- Risk assessment

Tutorials will be devoted to cleanroom requirements, establishing control, cleanroom operations and demonstrating control.

WWW.ISCC2018.COM (information and registration)
SCIENTIFIC.COMMITTEE@ISCC2018.COM (submission of abstracts)

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MORE ABOUT LESS

'Design in Vacuum' was the title of the first DSPE Knowledge Day, which was organised at the end of June in Eindhoven, the Netherlands. The meeting provided ample opportunities to exchange ideas and concepts between precision engineering specialists who have to deal with challenging problems associated with the combination of micro- and even nano-precision in severe ultra-high vacuum environments.

AUTHOR'S NOTE

Frans Zuurveen is a freelance writer who lives in Vlissingen, the Netherlands.

FRANS ZUURVEEN

To start, Sven Pekelder highlighted the activities of the Settels Savenije group of companies, whose former Philips premises formed the venue for this first DSPE Knowledge Session (Figure 1). Among other subjects Settels Savenije concentrates on the development of fixation, manipulation and movement of precision-mechanisms in challenging environments, including vacuum conditions.

Vacuum principles

Pekelder's colleague Gerrit van der Straaten emphasised the 'emptiness' of an ultra-high vacuum (UHV) with a pressure of no more than 10^{-11} bar. At this pressure the mean free path of molecules is much larger than the vacuum recipient dimensions, which means that molecules are free to move without colliding with each other. Nevertheless, one litre of this extremely high vacuum still comprises 10^8 molecules. A really 'empty' space cannot be attained: materials in the vacuum recipient evaporate molecules and moreover leakage and diffusion cannot be avoided completely. Because the molecules in a high vacuum can move freely without mutual collisions the usual Navier-Stokes flow principles are not suitable in this so-called molecular flow. In between these regimes there can be Knudsen flow, named after the Danish scientist Martin Knudsen, who discovered that in such conditions the number of molecules that pass is proportional to gas pressure and inversely proportional to molecular mass.

But when and why is it indispensable to create a vacuum environment? A rough vacuum between 0.3 bar and 1 mbar is applied to generate forces and to prevent heat transfer, but this will not be addressed further. Vacuum systems with pressures between 10^{-3} and 10^{-10} mbar are required to avoid contamination of products, to evaporate materials in vacuum deposition and magnetron sputtering systems, and to avoid absorption of energy. In addition, UHV conditions are of course indispensable to create absence of contamination and long mean free paths for electrons and ions in, for example, FEI electron microscopes.

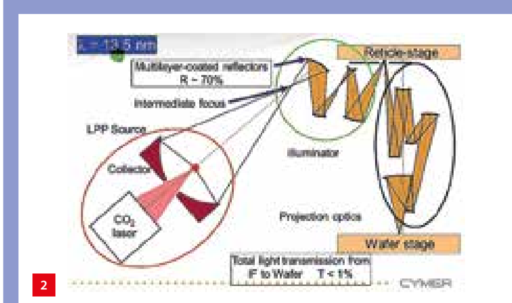
EUV-related systems

Van der Straaten showed some examples of vacuum constructions enclosing the vacuum or creating essential functions inside the vacuum environment. His main message was that since the best vacuum is an empty one, a systems approach should be used to determine which function to solve where (in or outside the vacuum) and how.

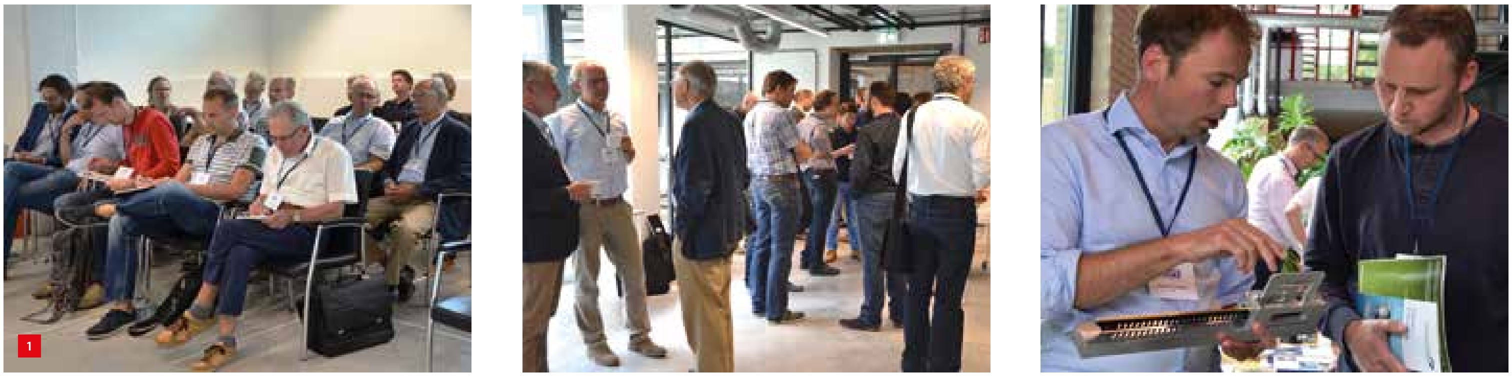
EUV

Following Moore's law – the doubling per two years of the number of transistors in an integrated circuit – ever shorter wavelengths are required for the lithography in wafer steppers, because according to the Airy criterion the smallest distance of two objects that can still be distinguished as separate objects is proportional to the wavelength of the used radiation. That is why ASML has continuously been trying to apply UV radiation with smaller wavelengths. This ultimately resulted in steppers of the last generation making use of Extreme UV (EUV) with a wavelength of only 13.5 nm. As EUV is strongly absorbed in a normal atmosphere, vacuum is required in the vessel.

The disadvantage of EUV is that 'conventional' high-resolution lenses cannot be used because EUV beams are not able to travel through glass or other refractive materials. Hence, EUV radiation can only be focussed with special mirrors, see Figure 2. For a wavelength of 13.5 nm, these mirrors are provided with an Mo-Si multilayer coating. This enables the reflection of 13.5 nm EUV but nearly extinguishes the reflection of nearby wavelengths according to Bragg's interference principle. The transmission efficiency of one coated mirror amounts to 70%, obviously rather poor but still workable with a total transmission from the first focus to the wafer of only 1%.



2 *The principle of an EUV source with an optical chain of multilayer-coated concave mirrors, which image a reticle pattern in 13.5 nm wavelength EUV on a silicon wafer. (Source: Cymer)*



Several examples were related to EUV-sources or systems working with EUV radiation, which poses additional challenges because of the contamination and radiation involved (for a background note on EUV see the box).

Precision UHV-compatible actuators

Maurice Teuwen highlighted the activities of Janssen Precision Engineering (JPE). His firm aims to be an expert partner for project-based development of high-precision systems. JPE delivers high-tech special products for groundbreaking scientific experiments with nanoscale positioning in UHV environments.

A good example is an actuator system with six degrees of freedom, formed as a hexapod, see Figure 3. It has been developed for a specific electron-optical application, where no commercially available stage was available to fulfil all stringent requirements. The JPE stage combines nanometer-resolution with sub-mm ranges. Three times two piezo-electric elements drive levers pivoting around earth-coupled hinges. Each of the three lever combinations is monolithically wire-spark eroded from one thick aluminium plate. Each unit thus provides two degrees of freedom to position an electron-optical image plane on top of the mechanism, which is positioned in an ultra-high 10^{-9} mbar vacuum, which is needed to provide a long mean free – non-magnetic – path for electrons, as explained previously.

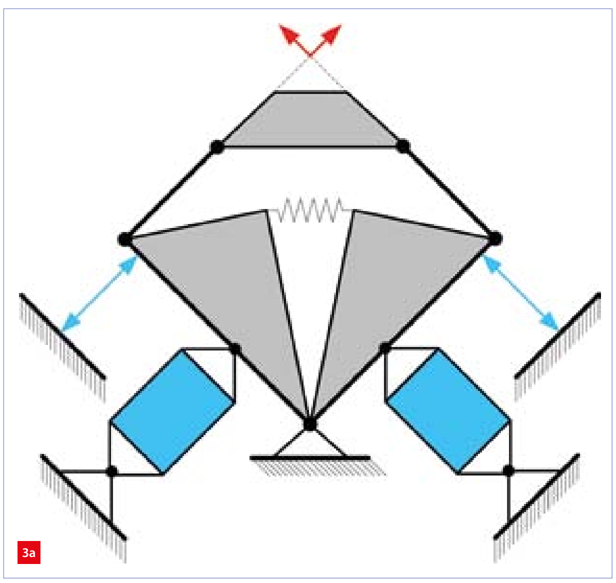
Another example of JPE's engineering expertise is an UHV stepping actuator, see Figure 4 (and the article on page 34 ff). This actuator provides a solution for demanding applications where a remote outside-vacuum actuator cannot be applied. The inside of the actuator houses proven technology with a stepper motor, screw spindle and ball-circulating nut, provided with common lubricant. This technology is forbidden in UHV conditions, of course, because of the high outgassing of lubricant. However, thanks to the complete leak-free welding of the actuator housing, the UHV-hostile inside environment is completely separated from the ultra-clean UHV outside. With a push-pull load capability of over 300 N, a stroke of more than 10 mm and a resolution of 2.5 nm at 10^{-9} mbar vacuum, it outclasses competitive systems.

Creating vacuum

Ronald Sheriff explained how Pfeiffer Vacuum helps customers to create a vacuum according to their specific demands. His company supplies solutions for creating, measuring and analysing vacuum. In 1890, Arthur Pfeiffer

1 *Impressions of the DSPE Knowledge Session 'Design in Vacuum'.*

3 *Actuator system with six degrees of freedom developed by JPE as three monolithically eroded lever systems.*
(a) Schematic drawing of one lever system.
(b) Realisation.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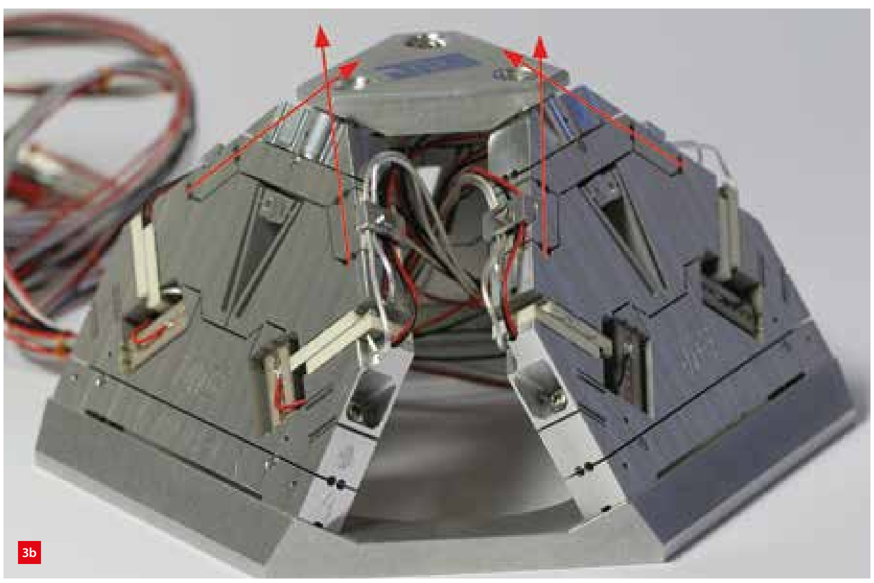
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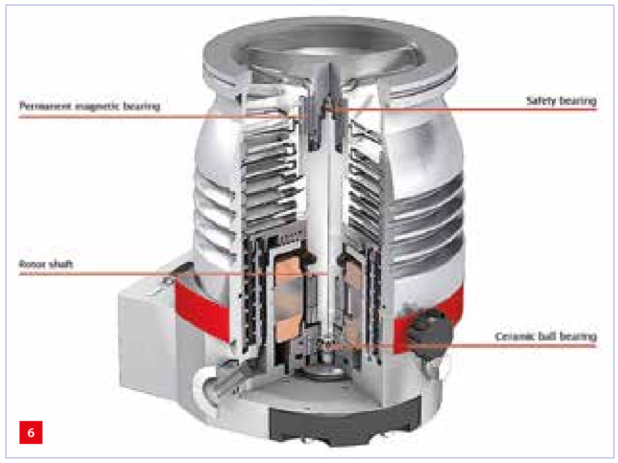


4 *A stepping actuator with a resolution of 2.5 nm designed by JPE for UHV applications. The hermetically closed inside houses proven technology with a screw spindle and stepper motor.*

5 *An example of a Pfeiffer fore-vacuum pump, the ACP 15 with a maximum pumping speed of 14 m^3/h. It is a dry compact multi-stage Roots pump type.*
(a) Exterior view.
(b) Interior with two synchronously counter-rotating rotors in figure-eight configuration.

6 *A cross-section of a Pfeiffer HiPace compact turbo-molecular pump with hybrid bearings: a ceramic-ball bearing on the fore-vacuum side and a permanent-magnetic radial bearing on the high-vacuum side. The pump is equipped with a safety bearing to support the rotor in case of failing electronics.*

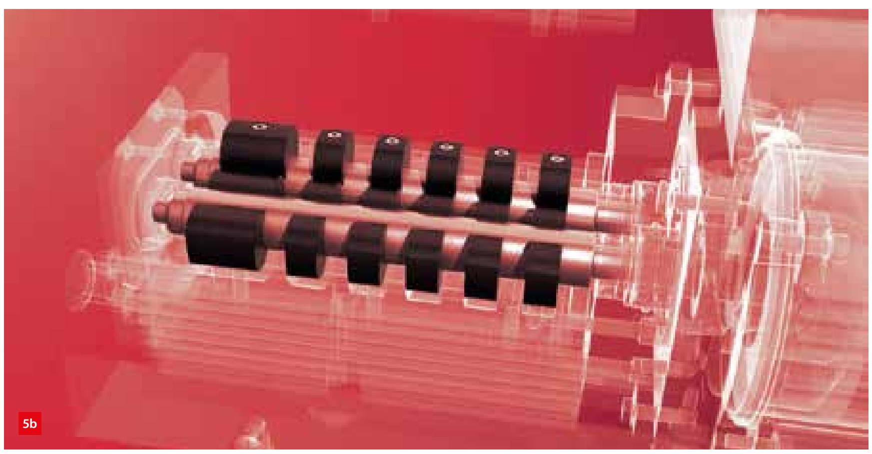
founded the company and invented the ‘oleo-pneumatic’ pump to create a ‘rough’ vacuum. Similar fore-vacuum pumps, see Figure 5, must still be used today because UHV creating devices cannot evacuate a chamber directly into atmospheric air.
To attain a UHV environment, Pfeiffer delivers turbo-molecular pumps. The working principle of these pumps is the forcing of gas molecules in a specific direction by repeated collisions with moving solid surfaces. These surfaces are the vanes of a rapidly spinning fan rotor, which hit gas molecules from the inlet of the pump towards the exhaust being coupled to the fore-vacuum pump, see Figure 6.

Pfeiffer turbo-molecular pumps are available with two different bearing types: a hybrid system with a combination of a ceramic-ball bearing on the fore-vacuum side and a permanent-magnetic radial bearing on the high-vacuum side, and a fully active magnetic bearing system in which the rotor is levitated with absolutely no contact or wear. In both cases the rotor is equipped with a safety ball bearing to prevent damage should the electronic stabilising system fall down.

Encapsulating vacuum

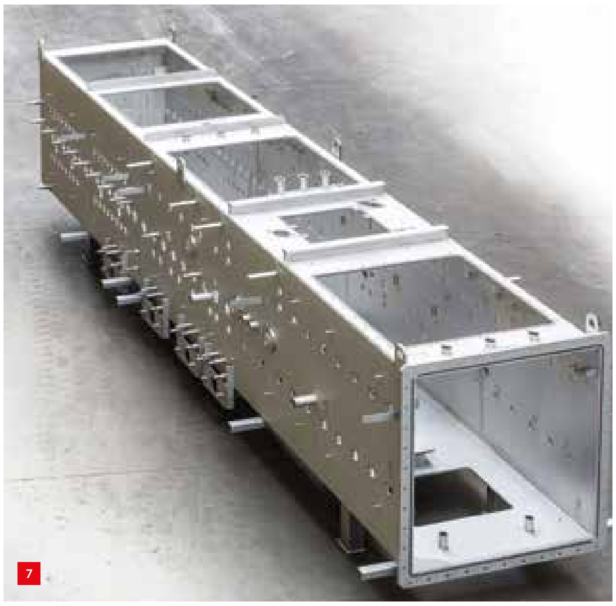
Tijs Teepen introduced Vernooy Vacuum Engineering, part of the Masévon Group, as a high-tech parts and weld assembly manufacturer for the production of vacuum recipients from stainless steel, titanium or aluminium. Such vacuum products vary from high-precision parts to large weld assemblies up to 3,500 kg. The Vernooy craftsmanship combines not only machining and welding experience but also the attainment of extreme cleanliness to avoid contamination of the UHV vacuum environment.

Figure 7 shows an example of a complicated Vernooy Vacuum product, a large vacuum chamber welded as an assembly of many separately machined parts with a lot of accurately positioned feedthroughs. Ribs are added to provide stiffness for the milling of O-ring grooves. This product shows that specified position and alignment accuracies are heavily correlated with the decision to pre-mill components or to mill the final welded assembly.
The design of vacuum chambers is guided by their manufacturability and is aimed at the avoidance of porosities and narrow gas inclusions (virtual leaks).
Another important design aspect is the enabling of short production times and high accuracies of the final product.
Important factors to reach ultimate UHV conditions are cleanliness and the absence of roughness of vacuum walls and sealing surfaces. The lead time and chamber quality largely depend on the skills of the workers on the shop floor.



7 *A vacuum chamber manufactured by Vernooy, with dimensions of about 4,000 x 800 x 800 mm³ for testing a stage in vacuum conditions. It consists of many separately machined parts with many accurately positioned feedthroughs. Parallelism tolerances are as tight as 100 μm.*

8 *Transmission electron microscope (TEM). (a) Schematic TEM principle with indicated connections to vacuum pumps. (b) Vacuum system. PIR: pirani vacuum measuring gauge; PP: pirani-penning gauge; IGP: ion-getter pump; TMP: turbo-molecular pump; PVP: pre-vacuum pump; CCG: cold-cathode gauge; X log: FEI-indication for relative vacuum pressure X, scaled from 1 to 100.*

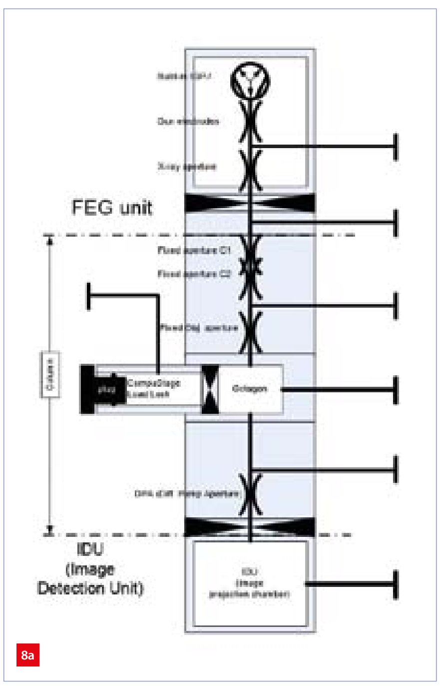


7

They translate the ideas of designers into a real UHV precision product.

Vacuum in electron microscopes

Some decades ago, Philips Electron Optics became part of FEI Company, which has recently been acquired by Thermo Fisher Scientific. High and ultra-high vacuum are the supporting factors for their electron microscopes, because electrons, to be regarded as short-wave radiation, have to move freely in a contamination-free environment. "The devil is in the details", Rients de Groot said, meaning that minor problems with O-rings, for example, may spoil the sophisticated design by electron-optical specialists. It is remarkable to see that mechanical annoyances from the seventies still persist today.



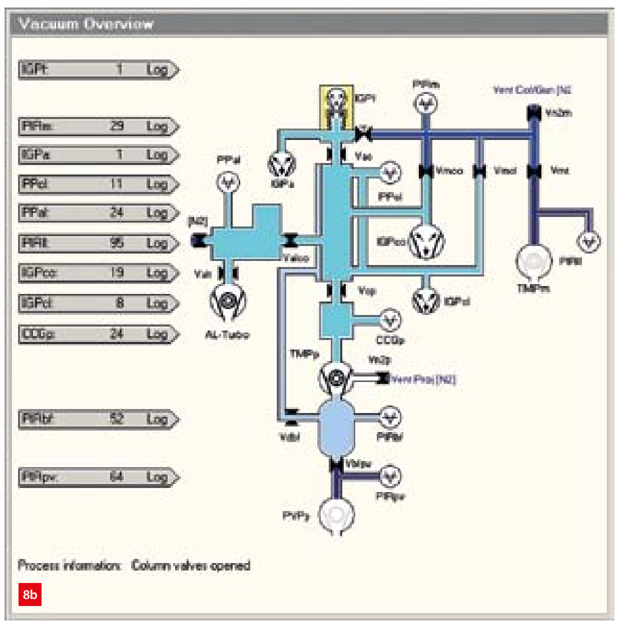
8a

Optically a TEM (transmission electron microscope), see Figure 8a, is comparable with a slide projector for visible light. In a TEM the electron source is an extremely sharp field-emission tungsten anode at a voltage of more than 100 kV. The emitted electrons are focussed onto an ultra-thin specimen using a series of two or three condenser lenses. The specimen essentially has to be thin because the electrons move through it, making the differences in transmission ratio – among other factors – responsible for the creation of an image. This creation takes place thanks to a number of electro-magnetic imaging lenses behind the specimen, forming an image either on a phosphoric screen in the imaging chamber, or on a photographic plate or in a video camera.

The functioning of a TEM and the creation of HV and UHV make clear that the column of such a microscope is equipped with a lot of pumping and vacuum measuring devices and still more sealings between merging mechanical parts. Figure 8b illustrates the vacuum system of a TEM. Ion-getter pumps are necessary to create UHV in the field-emission chamber, while turbo-molecular and ion-getter pumps are needed to create a vacuum around the specimen and in the imaging chamber. The specimen chamber pressure has to be lower than 10^{-6} mbar, the partial H_2O pressure may not exceed $5 \cdot 10^{-8}$ mbar and the partial hydrocarbon pressure C_xH_y must be lower than 10^{-10} mbar in order to prevent contamination or etching of the carefully prepared and often precious specimen.

The TEM column and accessories accommodate many opportunities for minor leaks. In that respect O-ring seal constructions are notorious. O-rings are made from synthetic rubber, a fluor polymer, for example, with the brand name Viton. De Groot explained that rather simple design rules help to prevent O-ring leaks and virtual leaks. Important is the requirement that machining marks in the bottom of an O-ring groove are concentric, see Figure 9a.

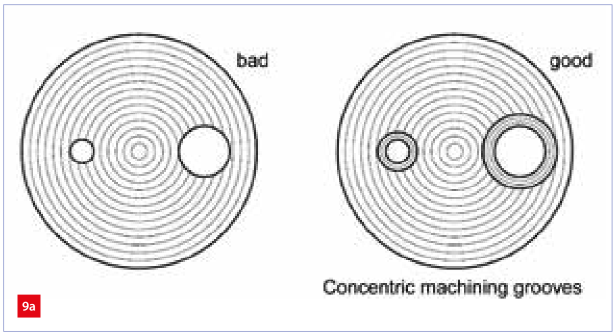
A double O-ring and an extra pumping channel connected with a fore-vacuum space help to maintain a good HV level (guard vacuum), see Figure 9b. All O-ring groove constructions need air-venting grooves on the vacuum side to prevent trapped volumes causing virtual leaks. Other design rules prescribe vents in screws or screw holes to prevent trapping of gases, see Figure 9c. Last but not least, the usage of vacuum grease must be avoided. This may help to stop leaking for a short period, but causes so-called vacuum spikes and ultimately vacuum contamination.

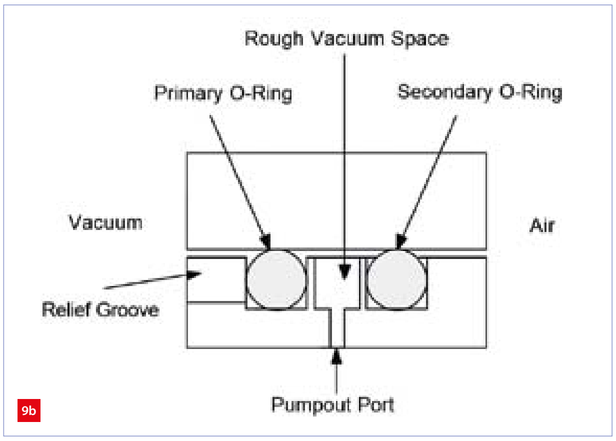


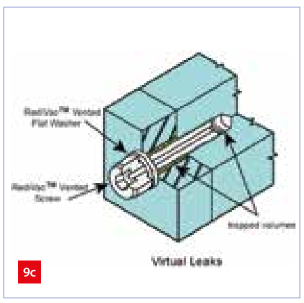
8b

To conclude

“The best vacuum is an empty vacuum”, one of the speakers at the DSPE Knowledge Day ‘Design in Vacuum’ said. This is more than self-evident, but the participants most certainly learned that even the best vacuum is far from ‘empty’. As was the Settels Savenije room where this symposium took place, demonstrating that this DSPE Knowledge Day tasted very moreish. ■







9 *Practical vacuum design rules.*
(a) Machining marks at the bottom of an O-ring groove should be concentric. (Source: CERN Accelerator School, Platja d’Aro, Spain, 2006, -VAT - Kurt Sonderegger)
(b) A correct double-O-ring application with relief groove to pump out trapped gas volumes. (Source: Phil Danielson, R&D Magazine, 2004)
(c) Screws need venting holes to prevent trapping of gases. (Source: UC Components)

Plasma assisted contamination

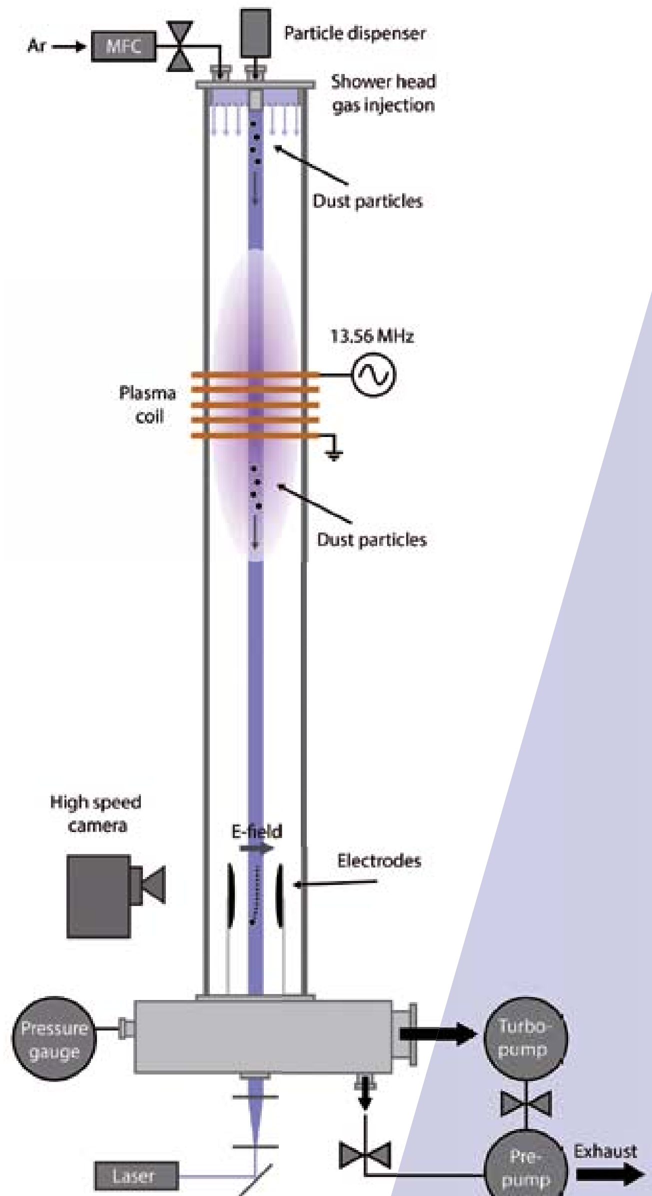


Figure 1.

Schematic drawing of the Plasma Particle Charging Investigation (PPCI) setup, which indicates the main elements of the system. Particles are injected at the top, they pass through plasma, which charges them. Afterwards the particle trajectories are studied using high speed imaging.

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control for ultra clean vacuum systems

For many high-tech applications such as high precision production, lithography, electron microscopy and nuclear fusion, nano- to micrometer sized particle contamination becomes an increasingly significant problem. Not only can particles contaminate delicate surfaces, also gas flows can be polluted by them. Both kinds of particle contamination can be controlled using ionized gases, named plasmas. Plasmas, consisting amongst others of free electrons, ions and atoms, are able to electrically-charge particles of any kind.

Utilizing this complex but interesting phenomenon of plasma-charging, the path of particles can eventually be controlled using electric and/or magnetic fields, either externally applied or induced by the plasma itself. To develop applications based on this concept further, there is an urgent need for deeper knowledge about the charging dynamics when these particles enter and leave a plasma region.

Complex plasmas

With the eye on a wide range of applications, the Eindhoven University of Technology (TU/e) focusses more than ever on the field of Complex Plasmas, i.e. the interaction between fine particles and plasmas. Many of these research projects are (partly) funded by high-tech industrial partners with as ultimate example the research project enabling the development of plasma assisted contamination control for ultra-clean vacuum systems. It highlights the strong collaboration between the TU/e's High Tech Systems Center (HTSC), the authors' research group and the industrial partner VDL- ETG.

Plasma Particle Charging Investigation

Within this project the Plasma Particle Charging Investigation (PPCI) setup has been developed and realized. Results of the PPCI setup can directly be translated into applications due to the close collaboration with a PhD candidate working within the department of Mechanical Engineering of the TU/e. In the PPCI setup ultrafine particles are injected at the top of the system, after which they pass through an inductively coupled plasma. The principles of plasma charging and decharging are studied by visualizing the particle trajectories in a region of known electric field, using high power laser scattering and a high speed camera. From the particle trajectories, the known applied electric field and a physical model for residual plasma shielding, the particle charge is pinpointed for a large range of gas pressures, particle sizes and shapes, particle materials (organic, metallic and dielectric) and particle and gas velocities. The PPCI setup is designed to be highly flexible.

Its core, a square glass tube of 1 meter in length, makes it possible to research many different plasma sources. Furthermore, with this configuration we can study the fundamental processes in different regions of the plasma, for instance in the plasma bulk, in the plasma space charge region near surfaces and even in the plasma afterglow. It is the combination of the developed complex plasma model and the unique setup that more insight can be given into the secrets behind plasma charging and plasma shielding. The first results, having a significant impact on the field will be published soon and many more interesting experiments are about to be conducted to help pushing the limits of the high-tech industry.

B. van Minderhout [1], T. Peijnenburg [2,3] and J. Beckers [1]

MEETING SUPREME CLEANLINESS STANDARDS RELIABLY IN VOLUME MANUFACTURING

AUTHOR'S NOTE

Doris Schulz is a journalist. Her agency, based in Korntal, Germany, specialises in PR solutions for technical products and services. This article was commissioned by Ecoclean (previously Dürr Ecoclean), part of the SBS Ecoclean Group based in Frankfurt, Germany. Ecoclean is engaged in the development, production and distribution of solutions for industrial cleaning and wet chemical surface treatment.

www.schulzpressetext.de
www.ecoclean-group.net

Part cleanliness specifications limiting particulates to the single-digit micrometer range and below while also imposing ultra-exacting thresholds for film-type contaminants are routinely imposed in diverse industries today. Achieving such figures with full process reliability in volume manufacturing requires perfectly adapted cleaning solutions. The Ecoclean view.

DORIS SCHULZ

In industrial segments such as semiconductors, measuring instruments, precision devices, micro-technology and optical systems, demands on the performance and reliability of parts and components have risen steeply. The trend towards miniaturisation and functional integration gives rise to ever more complex geometries. Developments, such as lithography machines using extreme ultraviolet radiation, result in geometrically complex high-precision mechanical components that are becoming substantially larger and heavier. "With such parts, which may consist of diverse materials such as stainless steel, copper and aluminium alloys, hard metals, Zerodur, ceramics and plastics, we are now covering diameters in the 0.5 to 1,500 mm range. Weights vary from under 1 g to 500 kg", reports Volker Lehmann, Head of the Precision Applications Business Unit in the Ecoclean Group.

1 *Cleaning diverse parts and components to highly exacting standards of cleanliness calls for perfectly adapted equipment and process design.*

However, a feature shared by all these parts is that they must be processed to significantly more exacting standards of surface cleanliness (Figure 1). This applies to particle-type surface contaminants and film-type residues, stains and discolourations, but also to the biological and ionic contaminants encountered in some industries. Thus, where the maximum acceptable particle size used to be between 5 and 150 μm not too long ago, today's standards call for cleanliness figures in the single-digit micrometer range and below. On top of this requirement, key cleanliness limits regarding outgassing of organic and inorganic contaminants lie in the atomic percent range. Specific thresholds are defined in accordance with the given product material.

Process design

The basis for fulfilling such high demands reliably and cost-efficiently in a volume production context will typically be a multi-chamber ultrasonic cleaning system using eight to twelve wet stages and one or more cleaning chemicals tailored to suit the materials and contaminants involved. A standard feature of such ultra-fine cleaning technology consists of multi-frequency ultrasonic devices with flexible control of the ultrasonic frequency and intensity to meet the cleaning needs of diverse workpieces.

"As part of our process development, process parameters such as temperatures, ultrasound frequencies and treatment times are adapted to the product and contamination type.

Additional process engineering aspects, e.g., with a view to ensuring a good fluid exchange even in blind holes, capillaries and undercut areas, are likewise defined at this stage", Lehmann explains. A part shaped with an eye to surface cleaning needs will make it easier for the cleaning process to satisfy the specified requirements. A good quality surface finish (i.e., polished or ground) is another necessary condition. On drilled holes, burrs and sharp edges are undesirable. Likewise, blind holes and very narrow capillary passages should be avoided.

A further important aspect in process development is drying. Depending on the part's complexity and heat absorption capacity, either mere vacuum drying is employed or a combined process, e.g., with upstream infrared drying.

Part carriers

One issue to be addressed in process development is the design of part-specific product carriers such as rotary, tilting or stationary types. What matters is that these carriers must not mask the product to be cleaned, and that any carryover of contaminated fluid is prevented (Figure 2). The turning or tilting mechanism should allow for speed control and position adjustment. Optimum positioning of the part, taking into account its geometry, in conjunction with suitably designed mechanical functions of the bath system will greatly facilitate the fluid exchange, e.g., in blind holes. An indispensable property of carriers for ultra-clean parts is that they cause no damage to or deposit particles on the product and ensure 'abrasion-free' movements.

2 *Part carriers must neither obstruct the fluid flow to the product being cleaned, nor cause any carryover of cleaning media.*

Equipment design

Apart from process engineering and part carriers, the design of the cleaning system itself has a key impact on how well and how reliably the exacting cleanliness standards will be achieved. For example, the four-sided overflow feature developed by UCM (Ultrasonic Cleaning Machines, part of Ecoclean) ensures that the cleaning or rinsing fluid enters each tank from below, then rises up and runs over the edge on all sides. This causes a permanent flow inside the tank which, on the one hand, provides an intense treatment of each part. On the other hand, due to the large volume, the very small particles and other residue removed from the product are discharged from the tank straight away, so any re-contamination of parts during unloading and transfer operations is prevented.

3 *Automatic transfer systems are of an abrasion-free design to avoid bath contamination.*

"In addition, we strive for flow-optimised design of all equipment components so that foreign matter cannot accumulate anywhere in the system", Lehmann adds. Accordingly, the chambers and tanks possess no corners for contaminants to settle in. On equipment for ultra-clean applications, parts of the pipework are made of polyvinylidene difluoride (PVDF). This high-performance plastic material is noted for its abrasion strength and chemical resistance but also provides very smooth surfaces to which foreign matter will not adhere. PVDF pipes are welded by the BCF process to obtain bead and crevice-free joints. They are installed without any 90° elbows and are laid to a gradient. This ensures that the piping will always drain fully and no stagnant water can collect anywhere.

Special demands are also placed on the design of the automatic handling and transfer systems (Figure 3). Here the predominant objective is to avoid abrasion, i.e., to ensure that no foreign matter can enter the tanks. This can be achieved either with handling devices placed below the bath surface or via appropriately protected process equipment in combination with cleanroom-grade components such as, e.g., linear motion units.

Controlling the air flow regime within the system is another major item. "In order to generate a laminar flow, flow boxes are integrated into the roof of the system. However, it is often forgotten that the air will also hit the bath surface, disrupting the laminar flow. An optimum laminar flow can only be achieved with the aid of a suitable extraction feature, e.g., through a perforated floor", Volker Lehmann explains in conclusion. ■

4 *An optimum laminar flow can only be achieved with the aid of a suitable extraction feature, e.g., through a perforated floor.*

DREAMING OF A CLEAN VACUUM

An ultra-high or clean vacuum is the dream of many engineers. However, in terms of achievability it is almost comparable to dreaming of a white Christmas in the desert. Developments in deposition processes, analytical systems or lithographic equipment drive a continuing demand for ever-more pure/clean/perfect vacuum. We pay a lot to clean and purify a small volume of our dirty world and replace it with a holy vacuum. As we know, there is an enormous and reasonably good vacuum in outer space, a heaven for vacuum technologists and just as unreachable as an absolute vacuum on earth. Instead, this is a thought experiment down here.

AUTHORS' NOTE

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SVEN PEKELDER, GERRIT VAN DER STRAATEN AND PIET VAN RENS

We can dream of making use of the huge vacuum in outer space by transporting our processes up there. Like Elon Musk's dream of using a 1 mbar vacuum to reduce air resistance in the Hyperloop, we like to make use of the benefits of vacuum. In the recent past, people have realised dreams of moving carriages in vacuum. There are a lot of inventions for guided systems that are driven in vacuum, such as how to get rid of problems related to, for instance, material choices, or heat transfer in vacuum and debris minimisation in guides. How to avoid the use of grease or how to facilitate acceptable lubrication?

Designing (sub-)systems to use in vacuum is a challenge in itself, as is keeping all parts clean and fit for vacuum, the job of the engineer or manufacturer. In this article, we dream on and try to deal with some of the technical challenges of design for vacuum.

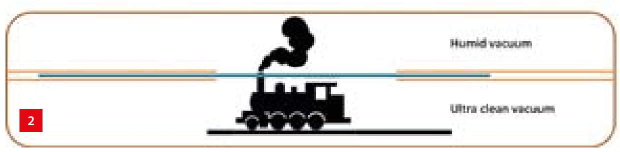
Our dream

Some of our colleagues cannot help themselves; even working in the office, they are thinking about the technical challenges they face in their hobbies (Figure 1). They dream of a heat-driven, autonomous, guided carriage in vacuum. The first impression of this is given in Figure 2.

This system is able to carry the energy for overcoming friction and accelerating the carriage for a reasonable period of time. Hereby we can avoid heavy cable schlepps, which are often a nightmare for engineers.

The energy is carried by $C_xH_y(OH)_z$ type of materials (ethanol/methanol). We assume that we can release this energy easily by adding oxygen, which results in some CO_2 and H_2O and a lot of energy, for example in the clean combustion of methanol ($2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$). Here we are, as usual, very realistic and foresee some challenges. How can we get rid of carbon dioxide and water and possibly some leftovers from the ethanol and/or oxygen? This is a typical type of vacuum problem. The use of process gases or fluids may be part of the vacuum system

1 *A miniature, fully functioning steam engine built by Vincent Schrik (one of Settels Savenije's engineers/architects).*



2 *An imaginary Settels stage.*

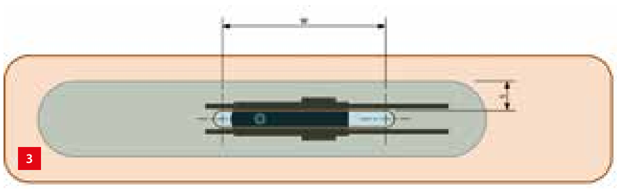
to start with, but you do not want any downsides from those gases, fluids or reaction products in the system and you do want to minimise their effect.

Of course, the first step in the design is to separate as thoroughly as possible the process room in which the transition of ethanol to carbon dioxide and water plus energy from the ultra-high-vacuum (UHV) part occurs. As the volumes of exhaust gases are relatively large, they need to be pumped away via a separate vacuum chamber. Additionally, the exhaust gases also need to be separated from the UHV room as well as possible, without compromising the easy movement of the in-vacuum steam-driven carriage. How can we effectively apply the energy we produce and how can we get rid of the energy that we cannot use for driving our carriage? We have already outlined more vacuum challenges than we can handle in a short article. We shall therefore concentrate on the in-practice and realistic parts of the challenge.

Pumping

Pumping for extremely high vacuum is very different from pumping for low vacuum. In our dream case, we have to get rid of a lot of CO_2 gas and water vapour in our low-vacuum chamber. So we need a high pumping speed under pre-vacuum (coarse, or humid, vacuum) conditions. In order to make it possible to keep the UHV around our carriage, we need to seal the two vacuum chambers with a flow resistance between them.

The gap in the seal is a real challenge. The width of the gap is two times the stroke of the moving stage (total width ≈ 2w in Figure 3). The flow length (L in Figure 3) is limited by the size of the chambers. The leakage can be calculated by the pressure difference over the gap. We assume that the pre-vacuum in the top room is below 10^{-3} mbar, so in the molecular flow regime. We want to avoid Knudsen flow or even viscous flow in the gap. In the case of viscous flow, the conductance in a gap of, e.g., 1 mm increases by many orders of magnitude and thus the gas flow through the gap increases (see the box on Knudsen flow).



3 *Top view of the stage in Figure 2. The blue area is the opening in the orange divider of the vacuum regimes; it determines the stroke of the stage. The grey area is indicating the (length of the) flow in the gap.*

For molecular flow the conductance C_{air} could be estimated as:

$$C_{air} \approx 630 \cdot W^2 \cdot t^2 \,/\, [\,(2W + 2t\,) \cdot L\,]$$

Here:

C_{air} = conductance [m³/s]
W = width of the gap [m]
t = height of the gap [m]
L = length of the gap [m]

With $W >> t$ the formula can be written as:

$$C_{air} \approx 630 \cdot W^2 \cdot t^2 \,/\, 2W \cdot L$$

And if $L \approx ¼\,W$ the conductance of the air gap is:

$$C_{air} \approx 1260 \cdot t^2$$

Knudsen flow

The Knudsen number is defined as:

$$Kn = \lambda / D$$

Here:

λ = mean free path [m]
D = characteristic dimension of the system [m]

For $Kn > 1$ the flow is characterised as molecular flow and for $Kn < 10^{-2}$ the flow type is viscous flow. For $10^{-2} < Kn < 1$ the flow is called Knudsen flow or transitional flow.
So with a decreasing Knudsen number the interaction between the molecules is increasing.

The leak through the gap can be calculated by the formula:

$$Q = C \cdot \Delta p$$

Here:

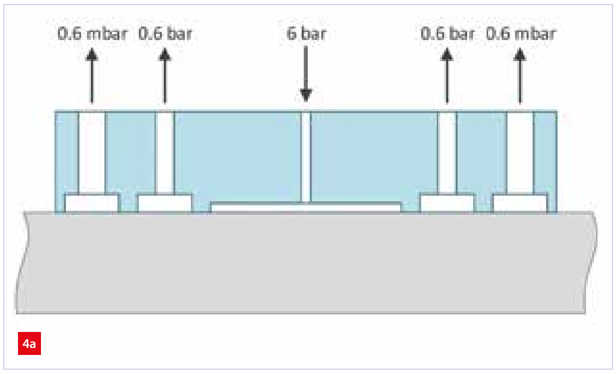
Q = gas flow through the gap [mbar.ℓ/s]
C = conductance of the gap [ℓ/s]
Δp = pressure differential over the gap [mbar]

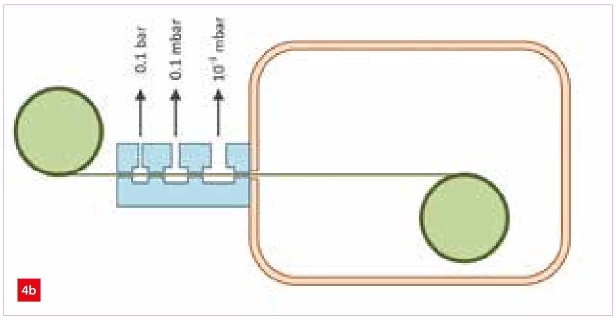
The gas flow through the pump can be calculated using the formula:

$$Q = p \cdot S_{eff}$$

Here:

p = pressure in the ultra-clean vacuum [mbar]
S_{eff} = effective pumping speed of the pump [ℓ/s]





4 *The stepwise approach in an air bearing in vacuum.*
(a) Schematic.
(b) Feed-in at a roll-to-roll process in vacuum.

The equilibrium of the gas flow through the gap and the pump capacity gives us the relation between the pressure level in the ultra-clean vacuum (UCV) and the pressure level in the coarse vacuum:

$$S_{\text{eff}} / C = p_{\text{coarse}} / p_{\text{UCV}}$$

We shall also, however, add a pump on the coarse-vacuum side to maintain as low a pressure as possible so as to minimise the contaminants leaking through the gap. The pressure level on the coarse vacuum side is determined by the equilibrium between the engine exhaust and the pump capacity. In this subsystem (coarse vacuum), the leak through the gap is negligible.

Differential vacuum

A leaking seal between UHV and the humid (coarse) vacuum asks for a stepwise approach, like with an air bearing, but then applicable in vacuum. Splitting up vacuum rooms, in order to allow a reasonable gap as a seal for molecular flows, is used in a lot of technical applications. For instance, if we use a gas bearing in vacuum we can pump the gas of the bearing away in a few steps (Figure 4).

Gas lock

Small parts and molecules can be driven by the laminar flow in a small gap. The speed of the flow in the gap of an air bearing between the chamber of 6 bar and the groove on 0.6 bar is very high. Particles that have dimensions < 10 μm will be blown away by that storm in the gap (in the order of 25 μm). The same is true of the gap between 0.6 bar and 6 mbar. Here too, we see a laminar flow that can carry small particles. There is still enough energy to accelerate them. Even if we bring the pressure down to lower the speed – as is done in a lot of vapour-carrying processes deployed in deposition processes in vacuum – we can still calculate the accelerations on large molecules. The calculations deal with Knudsen flows and molecular flow regimes and are proven to be precise and predictable when transporting molecules of known size, as well as keeping them away from surfaces or bringing them to preferred positions.

Sometimes you need a relatively large gap to reduce the resistance, generating enough kinetic energy in the driving gas molecules to stop and expel large/heavy molecules. What seems rather counterintuitive is that a larger gap ($\sim 10^{-4}$ - 10^{-3} m) in vacuum applications is better fitted for creating a barrier for unwanted species.

Heat transfer

In general, heat transfer can be achieved by conduction, convection and radiation. In vacuum, convection is negligible and conduction will only take place through structural elements. Keep in mind that the actual contact surface between two structural parts can be less than 5% of the nominal surface, depending on the Young's moduli of the materials, the surface roughness, the clamping force, etc. Typical values for contact resistance in vacuum are: 200-1000 $W.m^{-2}.K^{-1}$.

The formulas for heat transfer in vacuum are given by:

$$q_{\text{convection}} = (A/L)\cdot(T_2 - T_1)$$

$$q_{\text{convection}} = [\ \sigma / (\varepsilon_1^{-1} + \varepsilon_2^{-1} - 1)\ ]\cdot(T_2^{\ 4} - T_1^{\ 4})$$

Here:

q = heat transfer [W]
A = conducting/radiating surface [m^2]
L = conducting distance [m]
σ = Stefan-Boltzmann constant [$W.m^{-2}.K^{-4}$]
ε = emissivity factor [-]
T = temperature [K]

Heat transfer through vacuum can be achieved by radiation, although we need a large difference in temperature to make use of the radiation. For instance, the metal mask in a TV tube desorbs 250 Watt energy. To get rid of this, the thermal black mask raises its temperature over about 40 °C. In high-tech applications in vacuum, we also very often see the use of small flows of (inert) Helium through narrow gaps to transfer heat based on conduction. Low-pressure He gas in a gap between, e.g., a substrate or wafer and its supporting carrier can transport enough heat to keep the substrate or wafer at the same temperature as the carrier during processing (illumination, deposition or heat treatment). Of course, conduction through metals like copper Litze (multi-stranded) wires is also used in, for instance, electronic microscopes to take heat out of a sample.

For instance, we can calculate the required cross-section of a Litze wire to transfer the energy from the engine to the chamber wall:

$$q = \lambda \cdot (A/L) \cdot \Delta T$$

Here:

q = heat flux [W]
A = cross section of Litze cable [m^2]
L = length of the Litze cable [m]
ΔT = temperature gradient over Litze cable [K]

For a Litze wire of 1 m and a maximum allowed temperature gradient of 100 °C, we need a cross-section of 25 mm^2 to transfer 1 W from the engine to the chamber wall. For moving platforms, heat transfer by conduction is a challenge, and in this case radiation is dominant over conduction.

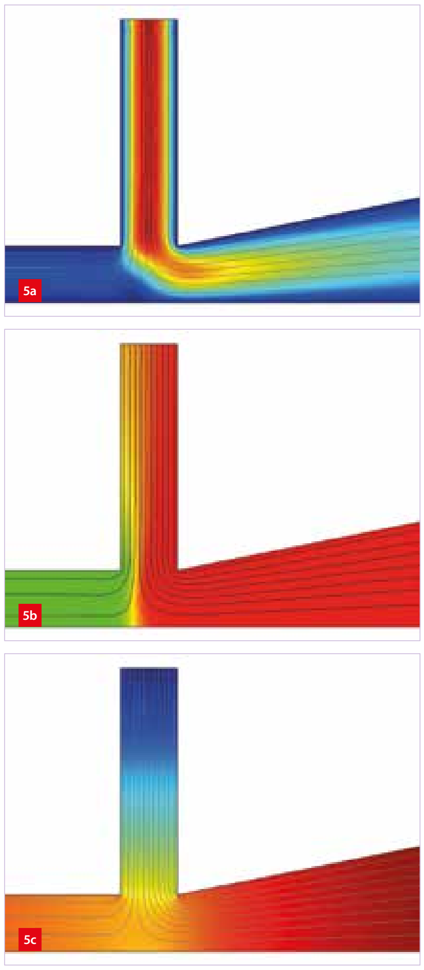
Lubrication

As the surfaces in vacuum are extremely clean, the coefficient of friction between two surfaces is higher than a same material combination would be under atmospheric conditions. For any application where low friction forces are required, e.g. roller bearings, locating pins or any other alignment mechanisms, grease is a reliable solution in terms of wear and lifetime. Unfortunately, the outgassing of grease on hydrocarbons is not acceptable in most vacuum systems. Alternatively, we can apply coatings to reduce the coefficient of friction. Although generally the vacuum performance of dry lubricated parts is better, we always do a residual gas analysis to verify outgassing. To verify mechanical performance, a pin-on-disc measurement can be performed in the same environmental conditions as the process in the vacuum chamber.

Moving platforms in vacuum also require some kind of guiding. When the stroke of the platform is relatively short, we can design elastic elements to support the end effector and let it move without the application of bearings. As in the Hyperloop, we can also use magnetic levitation (MagLev) to move the platform without the application of bearings. However, like our steam train, most off-the-shelf moving platforms use traditional types of lubricated bearings and, depending on the process requirements, lubrication of bearings is acceptable. Special measures may have to be taken to prevent the contaminating hydro-carbons from ending up where they are unwanted, e.g., by creating an insulating environment comparable to the differential vacuum gas lock described above.

Conclusion

Dreaming never stops at Settels Savenije, as it triggers creativity in the harsh and difficult world of vacuum. Trains may not yet be running in vacuum, but the technology, components and calculation/simulation methods (Figure 5) to do this are available. For the rare missing links, we are able to invent and we are ready to go back to the future. Much of the experience related to the design for vacuum systems comes from past work at Philips and in the semiconductor and display world. Nowadays, we are able to calculate flows, particle movement in flows, deposition, heat transfer and, of course, vacuum budgeting in all kind of vacuum regimes. ■



5 *During the design phase for vacuum systems, simulations are very important. This example shows results for molecules in a driving low-pressure gas.*
(a) Velocity profile.
(b) Concentration profile.
(c) Pressure profile.

Training

At The High Tech Institute, in cooperation with NEVAC, courses are available for design in vacuum. Knowledge has been collated in the "Basisboek Vacuumtechniek" (ISBN 9789090137766) by Suurmeijer et al. (English edition, "Vacuum Science and Technology", ISBN 9789090291376). The Basics & Design Principles for Ultra-clean Vacuum course (by content partner Mechatronics Academy, with Gerrit van der Straaten and Piet van Rens among the teachers) has been certified by euspen and DSPE within the ecp^2 framework.

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FROM UNCONSCIOUS INCOMPETENCE TO...

The need to ensure the cleanliness of components is still gaining importance within precision manufacturing. Both the quality and the cost, however, of cleaning processes are only partially under control – there is little knowledge concerning the necessary purity requirements and how to achieve them in practice. There is an 'unconscious incompetence'. This article aims to initiate a first step towards a 'conscious incompetence', resulting in an openness to improvement and a desire for more knowledge and understanding. Practical real-life (anonymous) situations will illustrate which improvements are possible.

CEES VAN DUIJN

AUTHOR'S NOTE

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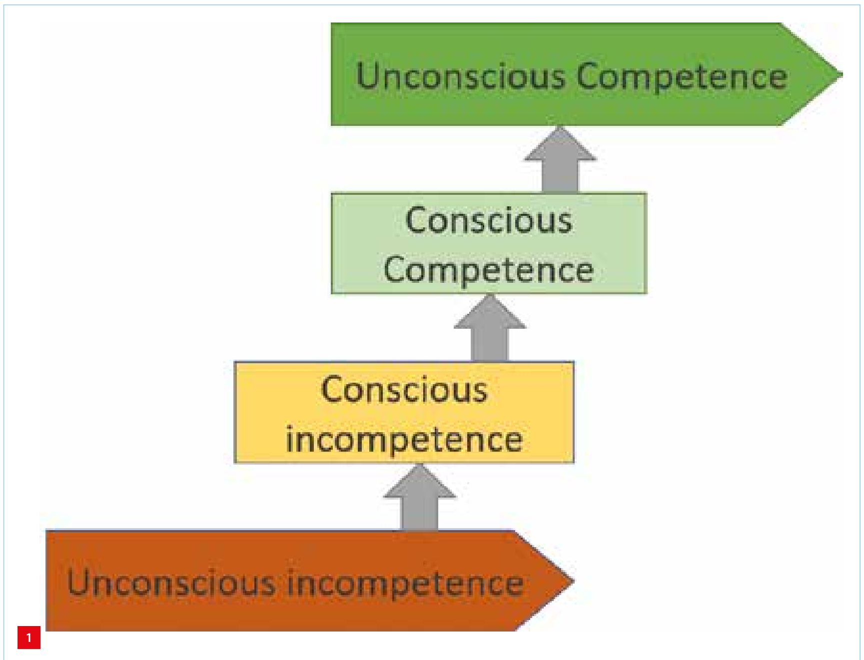
Precision manufacturing requires a lot of knowledge at all levels of a company, not only about the processes within the company, but also about those of the suppliers. Nothing can be left to chance. Materials must meet specifications, tools must be optimised, operations must be exactly specified and so on. Some of these things go well, because everyone involved in the process is competent; 'unconsciously competent', you could call it. A newcomer to this process will be initially unconsciously incompetent and then, by following a familiar learning curve, will first have to become consciously incompetent, then consciously competent and finally, just as his experienced colleagues, unconsciously competent (see Figure 1).



1 *The classic learning curve from unconscious incompetence, through conscious incompetence and then competence, to unconscious competence.*

Cleanliness is a requirement that, to an increasing extent over the course of time, is made for parts and complete products, but the consequences thereof are not always well understood (see also the article on page 5 ff). Around 1980, for the first time suppliers were confronted on a larger scale with the requirements for clean products. They were guided by experts from the companies who developed these requirements. Gradually this has created a situation where the suppliers have little knowledge concerning cleanliness requirements, while a growing number of companies are demanding clean products. Simultaneously, the expertise of the requesting parties has been mainly composed of knowledge copied from often very different cleanliness regimes, featuring product cleanliness requirements – for example in aerospace or pharma – that are hardly comparable to the requirements for precision products.

In practice, there is too much unconscious incompetence. As a result, ill-conceived investments are made in cleanrooms, cleaning plants and test equipment, while insufficient attention is paid to matters that have an equal effect on the resulting quality of the final products. Situations regularly arise where the requesting parties – sometimes rightly, sometimes wrongly – accuse suppliers of poor products. Often no one can pinpoint the root causes of disturbances by contamination in the final products.

Six conditions

Regarding the cleanliness of parts, the precision manufacturing process has a number of conditions that influence the final quality (see Figure 2):

1. Design
   First of all, the design of the product and its various parts determines to a large extent the ease with which a product can be cleaned.

2. Generation & Supply
   In the production (generation) or supply of parts, a role is played by starting materials, machining methods, use of coolants, quality of tools and many other things.
3. Precision cleaning
   In precision cleaning, the type of cleaning, the handling during cleaning, the quality of the cleaning agents and the like determine the cleanliness quality of the parts involved to a certain extent.

Then, assembly of the parts yields a final product. This phase can be divided into three different conditions that will determine the final quality of the product as regards to cleanliness:

4. Cleanroom quality
   First, the space in which the assembly is carried out is relevant. Products that are subject to cleanliness are usually assembled in a cleanroom. Cleanrooms can be classified into different classes. The most common class format is the format according to ISO 14644-1 (see page 6). Conventional cleanrooms for precision manufacturing are ISO-7 and ISO-6 classes.
5. Tools & Garments
   Next, the garments and tools used in the cleanroom will affect the final quality.
6. Skills
   Finally, the behaviour and work style of the employees will also affect the final quality.

The Pyramid of Case (after the Dutch pronunciation of the name of the author) schematically shows the six conditions that contribute to the quality of the cleanliness (see Figure 2a). There is a need for coordination between the different layers to guarantee quality, but also to avoid unnecessary costs.

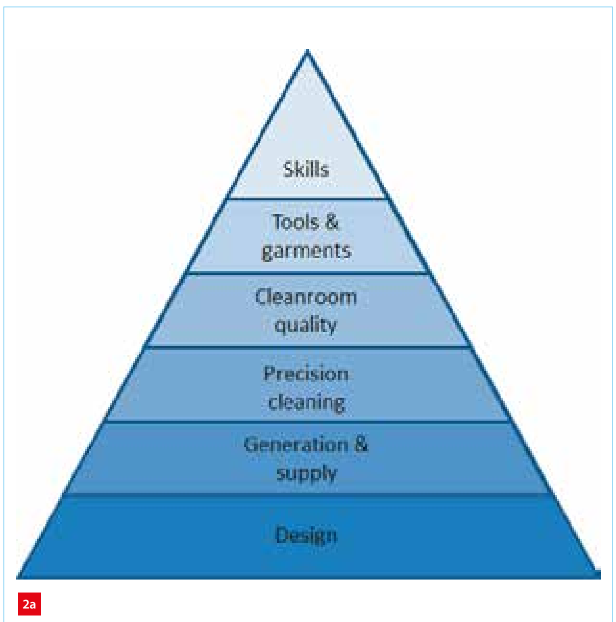
In practice, the different conditions are typically not well aligned (Figure 2b gives a more realistic view). As a result, the final quality is not always optimal and often costs are incurred unnecessarily. This is mainly explained by the fact that companies have too little knowledge concerning the necessary cleanliness requirements, while simultaneously there is a lack of knowledge concerning how such requirements need to be realised in practice. There it is, unconscious incompetence...

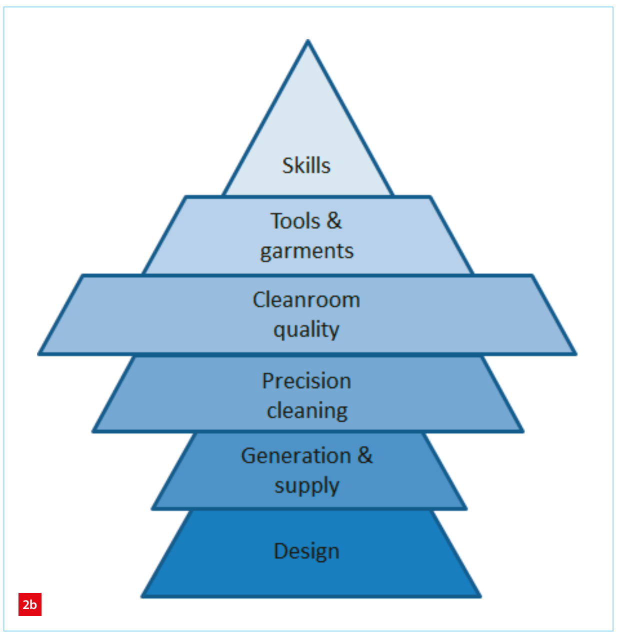
The design phase

In practice, product design has a great deal of influence on the cleanability of a product and thus on its final quality as regards to cleaning. Form, dimensions, material and operations all have their influence. Often, simple changes to a design can greatly improve the quality of cleaning and also reduce the manufacturing cost. Experience shows that the current quality of design leaves much to be desired. During the design phase there is too much focus on the functional requirements for a product, while only at a very late stage attention is given to the manufacturing and process implications.

Supply

The quality of supplied products is largely a grey area. There are hardly any complex assemblies of which it can be said with certainty that the entire supply chain has been identified (and released for clean production) and that no false deliveries (i.e., by non-released suppliers) will be made when unexpected supply problems turn up somewhere in the chain. In addition, buyers often make amendments to the chain when they want to acquire materials and products at lower costs. It also appears that most suppliers in the released chain do not have enough knowledge to guarantee the quality of the product regarding cleanability.





2 *The pyramid of Case, with the six conditions that contribute to the quality of cleanliness.*
(a) Stylistic, aligned view.
(b) More realistic view.

When releasing precision cleaning methods, the focus is usually on the removal of machining oils. There are many other types of contaminants that are known to be resistant to these cleaning methods, but suppliers do not always act on this information. Furthermore, the machining operation itself may already affect the final cleanability. An example is the processing temperature. If during the operation the products become too hot, the processing fluids may be burnt, leaving uncleanable waste on the products. The list of potentially uncleanable contaminants is long.

Along with the VCCN, I am developing a training course that will provide suppliers with basic knowledge in the field of contamination control, so that they can more confidently contribute to the cleanliness quality of the final products.

Precision cleaning

To achieve good and reliable cleaning, the following analysis is needed. First, which functions in the final product are affected by contamination? Next, how can this influence be observed? Based on answers to these, a method for measuring cleanliness can be selected. There are a great number of measurement methods to determine surface cleanliness. Often within a sector, one or two measurement methods are selected. Then a basic cleaning process is chosen. In this way, the complete process is established.

Precision manufacturing is characterised by a strong adherence to the initially selected process. Suppliers especially appear reluctant to deviate from this. Within the precision manufacturing industry, water-based cleaning was selected as the standard method (see Figure 3). That choice, made over thirty years ago, was not surprising: cleaning with solvents at the time was an issue because of the uncertainty around the application of environmental, fire safety and toxicity requirements.

Of course, developments in this area have not stopped over recent years. The result, generally speaking, is that solvent-based cleaning (see Figure 4) has developed many advantages over water-based cleaning. For very specific

3 *System for water-based cleaning.*

4 *System for solvent-based cleaning.*

cleaning problems, water-based cleaning may offer more possibilities than cleaning with solvents, but a water-based cleaning procedure is much more complex and prone to error (see Table 1).

I am often intrigued by people in precision manufacturing who are convinced that they are in full control of cleaning. ‘Unconscious incompetence’ springs to my mind immediately. Probably they are convinced that the processes, in so far as they have established them, are followed as much as possible and are likely to yield the results as obtained by the corresponding measurements. I am now quite sure that the procedures are far from complete, are rarely followed and the measurements generally leave much to be desired.

Furthermore, at least 90% of products are manufactured following excessively high standards of cleanliness, causing extremely high costs for a large percentage of the products. It explains in any case why there are relatively few problems: these will only occur for the 10% of the products that really have to be manufactured according to high standards; and a fairly high percentage of these will probably be also clean enough. However, it is remarkable that these high-cleanliness-standard products often exhibit intractable problems, which can only be identified with great effort. Solving these problems, so it appears, also results in extremely high costs – in addition to the already excessive costs for the aforementioned 90% of products.

Precision cleaning often proceeds without process control measurements. When doing measurements for companies, I regularly discover considerable problems in the various cleaning steps. That these problems usually do not appear in the final product is because the relevant contaminants are spread over several clean products measured simultaneously. That means that no short-term

Table 1. Comparison in terms of QLTC (Quality, Logistics, Technology, Cost) between water-based and solvent-based cleaning. Green and red indicate favourable and unfavourable, respectively.

Quality	*Reputation*	*Results*	*General applicability*	*Cross-contamination*
Water-based	Well-known process. In several markets to be replaced, because of cross-contamination and complexity issues. (aerospace, micro-electronics)	Results so-so, but accepted by the related markets. Many potential process failure mechanisms (cross-contamination, conditions of the liquids, algal bloom, quality of the purging, etc.)	Optimisation possible for special combinations of materials, specific contaminations and applications. Not recommended for a large range of applications	Combinations of materials resulting in colouring or material degradation (even particles from preceeding cleanings). Baking out by polluted ovens contaminating the products.
Solvent-based	Well-known process within a large range of markets. (In 2016 released for micro-electronics at ASML and FEI).	Relatively low rejection levels.	Applicable for a large range of processes.	Cross-contamination easily controlled. Combinations of materials possible.

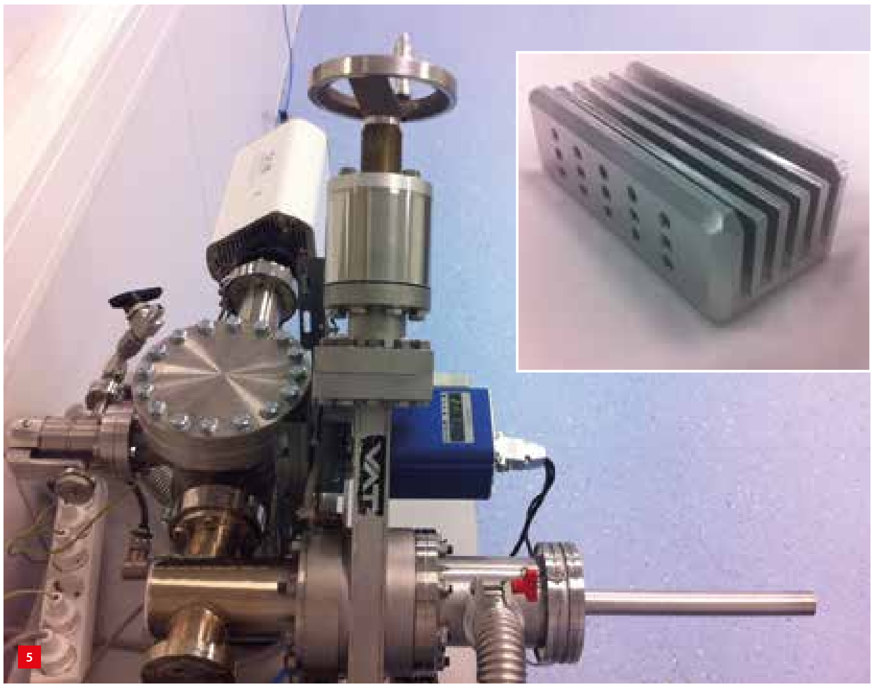
Logistics	*Duration*	*Specific requirements*	*Waste materials*	*Material complexity*
Water-based	Long-term process with several steps. Special drying and baking taking a long time.	Duration enlarged by 24 hour baking for grade-2 specific cleaning (ASML guidelines).	For intensive production permission needed from the authorities for the release of waste materials.	Most chemicals being complex. The large number of innovations making decisions about introduction of new products difficult.
Solvent-based	Limited number of short steps, almost identical for all products.	No baking needed.	No baking needed. Liquids easily regenerated within the system itself. Waste materials easily separated and transported using drums.	Chemicals very basic.

Technology / investments	*Floor space*	*Required equipment*	*Installation costs*	
Water-based	Large floor space.	Water supply and drain, electricity.	High installation costs.	
Solvent-based	Relatively small floor space required.	Electricity only.	Relatively low installation costs.	

Operational costs	*Purchase costs*	*Energy consumption*	*Staffing costs*	*Maintenance costs*
Water-based	Depends on load.	High energy consumption for water heating, drying and baking.	Reduction of staffing costs by transport robot possible.	Relatively low costs for chemicals. Relatively low other costs.
Solvent-based	Comparable to water-based.	Relative low energy usage. No baking needed.	Automatic transport inherent to the system.	Relatively low costs for chemicals. Relatively low other costs.

contamination can be observed. However, there are parts that are a continuous source of pollution, because they are not clean, and over time this does affect the quality of the final product.

From a hefty series of bad results, I offer this example. A cleaning line of a supplier of small parts was released by a leading customer. The quality was determined using residual gas analysis (RGA). Because the parts were very small, they were measured along with other products. No contamination was detected. I did a measurement with a test part using an RGA system that had been optimised for measuring such a test part (see Figure 5). The contamination had to be was measured again, because there



5 *RGA system for process control using test parts (see inset).*

was disbelief at the large value that was found. Both times the pollution in the released cleaning line was over 25 times higher than the specification.

Cleanroom

With precision cleaning, one almost always immediately thinks of a cleanroom. Usually, subconsciously one is aware that a cleanroom does not clean a product. Nevertheless, I have the impression that people assume that the better the cleanroom, the better the cleanliness of the products. In practice, most cleanrooms turn out to be hugely oversized. If the number of particles that is deposited on a product is being measured in an ISO-7 cleanroom at rest, then the result is less than one particle (size > 30 μm) per dm^2 per hour. In a well-cleaned cleanroom using the proper garments, it appears to be very difficult to have a contamination of less than 500 particles (> 30 μm) per dm^2 per hour (see Figure 6), as shown by measurements based on actual numbers of particles and not on so-called UV-luminescing particles.

6 *Particle deposition measurements in an ISO-7 cleanroom.*

Finally, a cleanroom is just an aid in being able to work rather cleanly in a simple way. The way of working determines the end product. My belief is that the desired cleanliness as related to particles, in an ISO-8 room as well, would be fairly easy to achieve, provided that the cleanliness of the cleanroom and used garments is in order, and most importantly, that the way of working is under control.

In addition, particle-related contamination is not the only concern: contamination by touching dirty surfaces and tools is at least as disastrous, and focusing on it is just as important. Nor is a cleanroom necessary to minimise this contamination. Only the discipline normally desired in a cleanroom is important. A well-trained employee can achieve the required cleanliness in an office. A cleanroom only makes it a whole lot easier to achieve the desired degree of cleanliness.

Tools and garments

Proper garments when working where cleanliness plays a role is of great importance. In a room that is not excessively qualified, it is not too difficult to get a clean product with the right garments. The environment during manufacturing is reasonably easily cleanable and by careful consideration of the performance of the operations, particle contamination can be kept fairly in hand.

However, in a highly qualified room, working with improper garments, it is very difficult to deliver a clean product. The heat flows around the body result in a fairly large flow away from the body. During the work, a large part of this flow will come close to the product. This flow carries both skin particles and dust particles from the garments, which can easily be deposited on the product. Measurements show that there is a big difference between garments that seal the body completely and garments that only partially seal the body and clothing. Between ill-fitting garments and no cleanroom garments, the difference is significantly less.

Contamination by touching polluted tools is also an important concern. In a cleanroom, it is easy to keep cleaning tools clean. The discipline to keep the tools clean, however, seems to be difficult to maintain. A much bigger problem is that sometimes tools are needed that are not present in the cleanroom. They can be brought in, but the required cleaning step is not always carried out as carefully. All in all, work preparation for clean manufacturing appears to be very important. Unfortunately, there are many examples in which this was not sufficiently recognised.

Contamination due to contact with dirty surfaces cannot always be avoided in practice. A very familiar and common situation is rubbing an itching nose with a glove that is then immediately used to touch a product. Another often underestimated situation is touching – for sometimes long periods – packaging materials, which at first seemed quite clean, but afterwards cause more contamination than anticipated.

Skills: experience and behaviour

Finally, behaviour and experience appear to be the most relevant factors that have an impact on the final result. Employees who have a good understanding of what contaminations can take place are not only alert, but are also able to provide feedback on many issues. Here, preventing an excessive workload is also important.

Recommendation

Based on my experience, the following recommendations are important in improving the reliability of the precision cleaning process. In particular, the management at suppliers should show a greater drive towards increasing the cleanliness competence within their company. In addition, management should also consider more carefully whether investments concerning cleanliness are well matched to other conditions that play a role in achieving the final cleanliness quality. ■

ENCAPSULATED BEFORE ENTERING VACUUM

A linear positioner has been designed by Janssen Precision Engineering for use in ultra-clean environments where outgassing and/or particle generation is critical. Within such environments the Nano Stepper Actuator, hermetically encapsulated before placement in the vacuum vessel, offers a solution for high-end positioning requirements. From Berlin to California, customers adopt this solution because of its true UHV-compatibility and optimal positioning performance.

BART VAN BREE

Introduction

When searching for a solution to position objects in a vacuum one traditionally has two basic options. The first and most traditional solution is the use of 'through-the-wall' motion. Typically some kind of actuator, manual or motorised, is located in normal ambient conditions and the linear or rotational motion is entered into the vacuum chamber via a feedthrough flange. At best this feedthrough is bellows-based and ultra-high vacuum (UHV) compatible, but very often it involves some kind of O-ring-sealed sliding mechanism.

Less standard are magnetic force-coupled feedthroughs or the use of liquid, ferrofluidic, seals. Positioning performance is limited because of the long distance between point of actuation and point of positioning. This kind of positioners is still widely used and offers a reliable and cost-effective solution for many users with less stringent positioning requirements.

The second option is the use of complete positioners in the vacuum environment, directly at the point of interest. This is especially beneficial when working with large vacuum vessels. Again, many solutions are available on the market. Although positioning performance is greatly increased, there are two major drawbacks.
Firstly, the introduction of high-outgassing materials in the vacuum vessel. These positioners are typically based on non-vacuum positioner concepts, which are made vacuum-compatible by replacing the 'dirty' materials with 'clean' materials. Examples are kapton wiring, vacuum-compatible greases and plastics like teflon and PEEK.
Secondly, reliability can become an issue because friction and wear of moving parts is increased, potentially causing failure and limiting lifetime. The increased wear also results in particle contamination.

A third option is to hermetically encapsulate the positioner before placing it in the vacuum vessel. It seems a logical solution but it is hardly ever seen, certainly not as an off-the-shelf product. The reason is probably that it is not merely an upgrade of an existing actuator but requires a dedicated design from the start. Just as the second option this will have optimal positioning performance, but it has several additional advantages. First and foremost, this allows the use of high-quality components within their normal operating conditions. There is no need for specials, alternative materials or non-standard coatings and greases.

As a result of this 'off-the-shelf' approach reliability and lifetime will be increased. The big advantage for the end user is that he or she does not need to worry about introducing unknown materials in the vacuum vessel, influencing the experiment or process. An example of this third option is a linear positioner that has been developed by JPE, the Nano Stepper Actuator for UHV (NSAU) [1].

NSAU features

The NSAU (Figure 1) is a linear positioner for use in ultra-clean environments where outgassing and/or particle generation is critical. Within such environments it offers a solution for high-end positioning requirements. Internally, a

1 *The NSAU, a linear positioner for UHV applications, from JPE.*

AUTHOR'S NOTE

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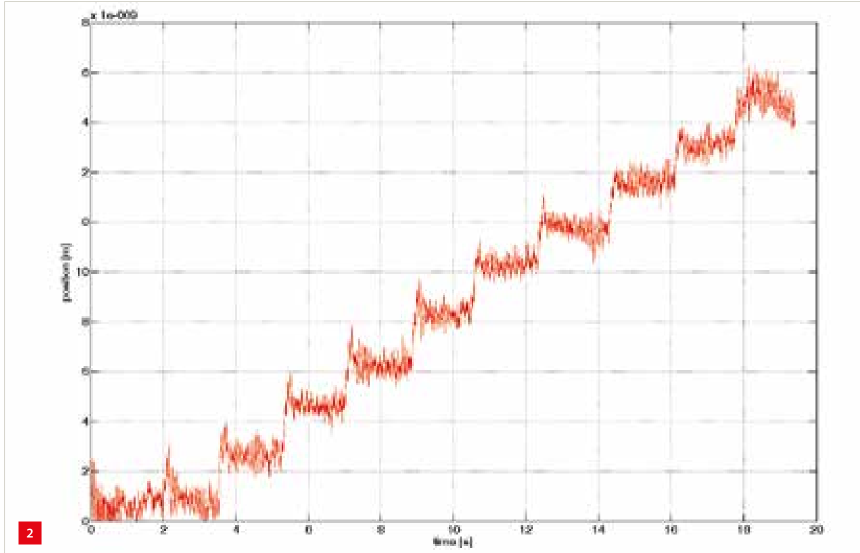
stepper motor fitted with an absolute encoder drives a gearing unit which turns a fine-pitched spindle. It combines a set of features that is aimed at allowing accurate positioning and making implementation in a vacuum vessel easy.

Hermetically sealed

The main feature of the NSAU is a welded stainless steel cover, which makes it UHV-compatible and prevents particle contamination from wear to the environment.
An edge-welded bellows allows linear motion output. The correct operation of the NSAU requires that the internal pressure remains above 950 mbar during its lifetime. This allows all internal components to operate at normal ambient conditions. The time before this pressure decrease is reached follows from $Q = dp \cdot V/dt$. Using the specified He leak rate $Q < 1 \cdot 10^{-9}$ mbar·ℓ/s, a pressure drop of 50 mbar and an estimated internal volume V of 0.25 ℓ, we get $dt = 1.25 \cdot 10^{10}$ s or 396 yrs. Clearly, this is not a matter of further consideration.

Nanometer positioning

A full step by the stepper motor will result in 50 nm motion output, but microstepping allows considerable finer positioning. Figure 2 shows the output when driven with 64-fold microstepping, equivalent to a theoretical step size of 0.8 nm.
Accurate positioning starts by combining an optimised structural design with high-quality standard components. Only then nanometer resolution and minimal hysteresis can be achieved. In the NSAU a top-performing gearing component between motor and spindle has been selected. It is backlash-free and has a superb stiffness between its high-speed input and low-speed output axes. The output axis drives a preloaded spindle, transferring rotation into the desired linear motion. Axial loads up to 300 N are possible, both in push and pull. The internal mechanical layout will transfer this load via the shortest route to the mounting flange, giving optimal actuation stiffness.



On-board absolute encoder

Adding external sensors to make a positioner work reliably is never desired, but is especially troublesome in UHV conditions. Therefore, the NSAU has been made self-sufficient. An absolute encoder is integrated on the stepper motor giving absolute position information, even after a power cycle (on/off), eliminating the need for homing. Redundancy is offered via end-switches at end-of-range and a thermal sensor on the stepper motor prevents overheating the motor.

No power dissipation at stand-still

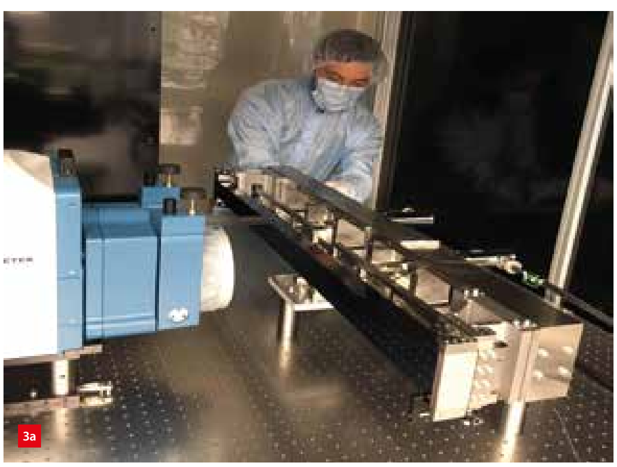
The self-locking behaviour of the NSAU allows a complete power off after reaching the desired position. When doing so not only the physical position will be maintained, but at power up also this position information is available again from the absolute encoder.

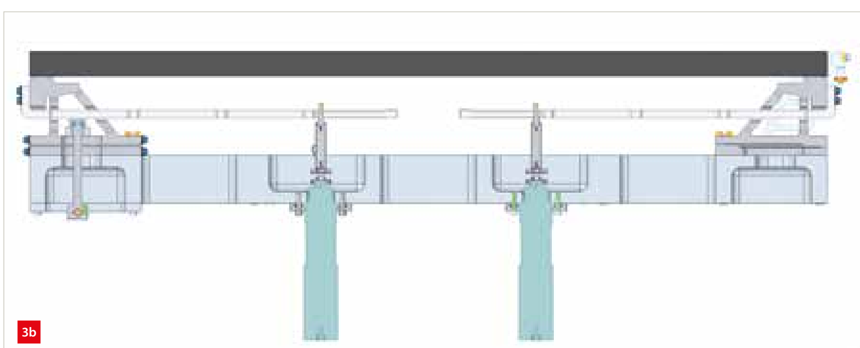
Easy interfacing

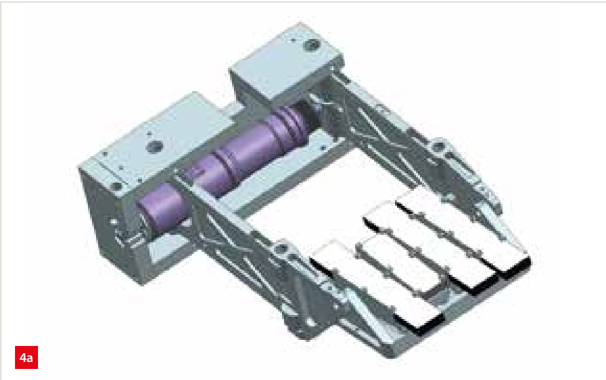
A simple flange offers an easy mechanical interface to position and clamp the NSAU in the user's set-up. Electrical interfacing is done via a single circular connector with glass ceramic insulator material, which also has a vacuum-compatible counterpart that can be used on cabling.
A dedicated controller can be delivered with the NSAU, but all interfacing complies with industry standards and it is compatible with many controller platforms.

2 *NSAU motion output measured with a laser interferometer in an unconditioned test environment.*

3 *SLAC test set-up*
(a) Realisation.
(b) The bending concept. Each NSAU (blue, vertical elements) drives a flexure, introducing a torque on the pivot points at the ends of the mirror (black beam).







4a

4b

4 *The mirror selection mechanism, driven by an NSAU, in the new High Transmission x-ray Spectrometer (HiTS).*
(a) Design of the mechanism.
(b) The HiTS will be placed in the expanding Energy Materials In-situ Laboratory at BESSY II.

Recent applications

SLAC National Accelerator Laboratory

X-rays are used to examine materials in the fields of energy production, electronics, environmental clean-up, new materials, nanotechnology, medicine, et cetera. At SLAC National Accelerator Laboratory (formerly Stanford Linear Accelerator Center) [2], in Menlo Park, California, USA, a next-generation x-ray focusing tool is being developed. It consists of an extremely smooth (sub-nanometer surface roughness), long and narrow mirror which needs to be bent into a barely perceptible curve. The so-called KB mirror benders are driven by two NSAU positioners; Figure 3 shows a prototype.

The NSAU was selected by SLAC after an extensive global search for available options. The combination of true UHV-compatibility, positioning performance, load capacity, and easy integration in their existing controller hardware was unbeaten.

Helmholtz-Zentrum Berlin

The BESSY II Synchrotron in Berlin, Germany, will allow the study of samples to a penetration depth of up to several nanometers. Complementary bulk spectroscopic methods allow measurements from a few hundreds nanometers up to several tens of micrometers. To bridge the gap in information depth, there is a need for a new instrument; the High Transmission x-ray Spectrometer (HiTS), which is being developed by JPE for Helmholtz-Zentrum Berlin [3]. Part of the spectrometer are two mirror selection units, each driven by an NSAU (Figure 4). In this case, the available space surrounding the HiTS is tight and personnel cannot come close enough for manual operation, so in-situ actuation is required.

The risk of mirror contamination with condensed gases or particles was seen as critical by the customer and the NSAU offered a perfect solution in the $5 \cdot 10^{-10}$ mbar environment. ■

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[1] www.janssenprecisionengineering.com/page/nano-stepper-actuator-ultra-high-vacuum-nsau
[2] www6.slac.stanford.edu
[3] www.helmholtz-berlin.de/index_en.html

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On 15 and 16 November 2017, the seventeenth edition of the Precision Fair will once again be the international meeting point for precision technology. At this free event in the NH Conference Centre Koningshof in Veldhoven, the Netherlands, visitors can become inspired by some 300 exhibitors (specialised companies and knowledge institutions), among which nearly 60 DSPE members.

The heart of the Precision Fair is the exhibition, which covers a wide array of fields, including optics, photonics, calibration, linear technology, measuring equipment, micro-assembly, motion control, piezo technology, precision tools, sensor technology, software and vision systems. A sneak preview of a few innovations on display is presented on the following pages.

The fair also features a two-day lecture programme crammed with presentations. Once again there is the opportunity to meet big science projects, such as CERN (nuclear research), ITER (nuclear fusion energy), ESS (European Spallation Source) and ESRF (European Synchrotron Radiation Facility). (Dutch) high-tech suppliers can learn about their recent technological developments and new tenders. The International Meet & Match Event will be hosted on both fair days as well. Preceding the fair, on Tuesday 14 November, the CERN Entrepreneurship Day will be organised.

Awards

At the end of each fair day, event partner DSPE will organise an award ceremony. On Wednesday 15 November, the Rien Koster Award will be presented to a mechatronics engineer/designer who has made a significant contribution to the field of mechatronics and precision engineering. On Thursday 16 November, the Wim van der Hoek Award will be presented to the person with the best graduation project in the field of design in mechanical engineering at one of the Dutch (or Belgian) universities of technology or applied sciences (see the nominations on page 62 ff).

Media partner Mikroniek will report on the highlights of the Precision Fair 2017 in its December issue.

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Impression of the Precision Fair 2016. (Photo: Mikrocentrum)

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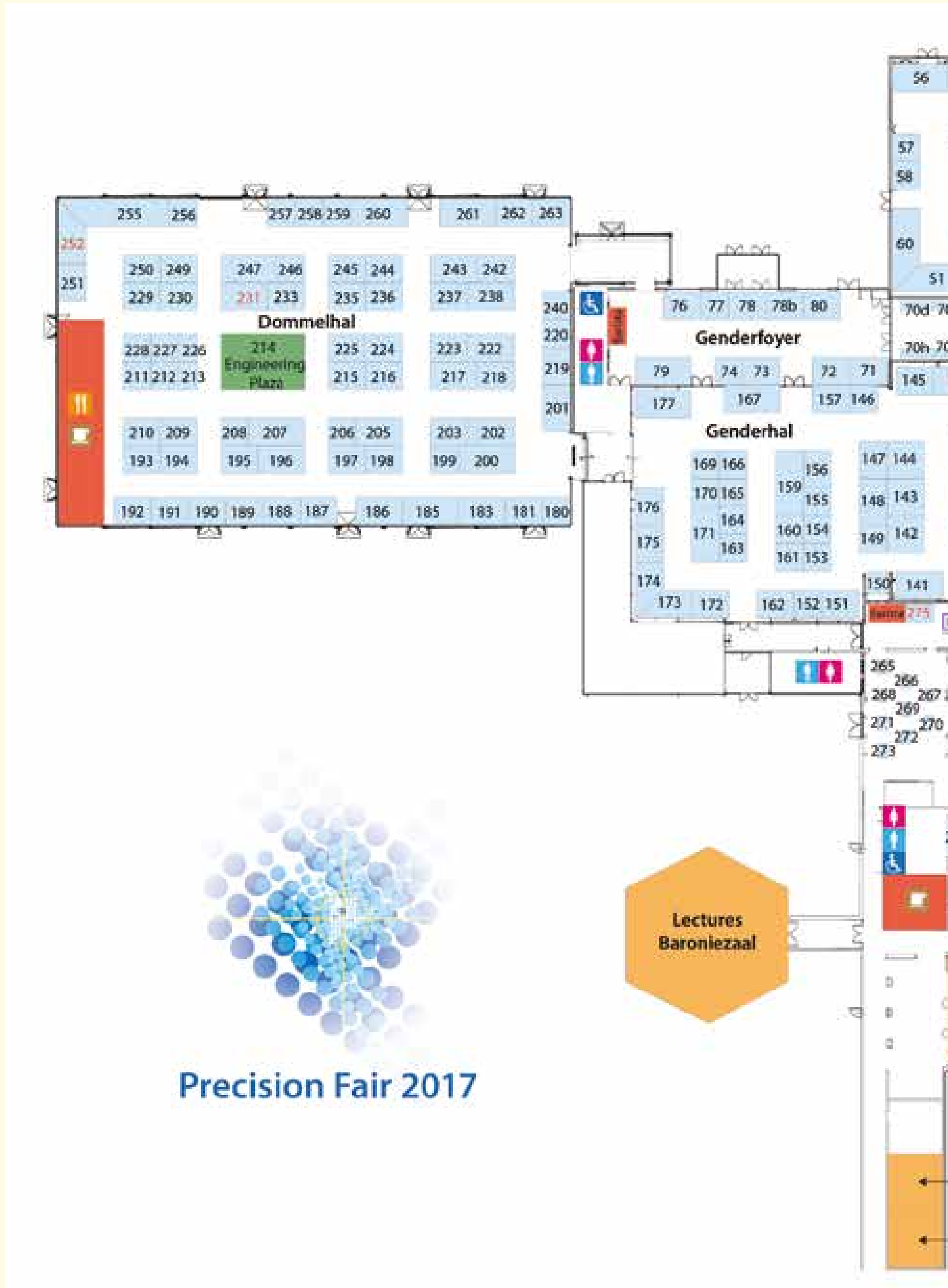

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281	PULSAR PHOTONICS GMBH	44	STEEN METROLOGY SYSTEMS	70B	VAN DER HOORN BUIGTECHNIEK
269	QSO INTEFEROMETER SYSTEMS AB	10	STEMMER IMAGING BV	70E	VAN HOOF GROEP BV
270	QUANTUMCLEAN GLOBAL TECHNOLOGIES	170	STT PRODUCTS BV	155	VAN HOORN CARBIDE NEDERLAND BV
256	RAYTECH BVBA	119	SUMIPRO	164	VARIASS GROUP
60	REITH LASER BV	31	T.S.G. GROUP	121	VARIODRIVE AANDRIJF- EN BESTURINGSTECHNIEK BV
149	RELIANCE PRECISION LTD.	216	TBP ELECTRONICS BV	273	VCCN
167	RENISHAW BENELUX BV	95	TE LINTELO SYSTEMS	112	VDL ENABLING TECHNOLOGIES GROUP EINDHOVEN BV
72	RI RESEARCH INSTRUMENTS GMBH	81	TECHNOBIS GROUP	18	VDL GL PRECISION
262	RJ LASERTECHNIK GMBH	07	TECHNOLOGY TWENTE BV	66	VDMA ELECTRONICS, MICRO AND NANO TECHNOLOGIES
54	RODRIGUEZ GMBH	213	TECHNOSOFT BVBA	176	VERNOOY VACUÜM ENGINEERING
14	ROELOFS MEETINSTRUMENTEN	148	TECNOTION	70G	VIA ENGINEERING DEURNE BV
46	ROFIN-BAASEL BENELUX BV	55	TEESING BV	48	VIRO ECHT BV
249	ROMEX BV	141	TEGEMA	174	VOSSEBELT PRECISIEBEWERKING BV
85	SALOMON'S METALEN BV	23	TELMASTAAL BV	145	VSL
96	SBN NEDERLAND BV	101	TER HOEK VONKEROSIE RIJSSEN BV	237	W.L. GORE & ASSOCIATES GMBH
79	SCHAEFFLER NEDERLAND BV	163	TEVEL TECHNIEK BV	35	WEISS NEDERLAND BV
41	SCHNEEBERGER GMBH	276	THE HOUSE OF TECHNOLOGY	245	WEISS TECHNIK NEDERLAND BV
01	SCHUT GEOMETRISCHE MEETTECHNIEK BV	197	THK GMBH	98	WERTH MESSTECHNIK GMBH
144	SENTECH B.V.	211	TIELTJES PRECISION PARTS BV	233	WIJDEVEN INDUCTIVE SOLUTIONS BV
191	SERVOMETER - A MW INDUSTRIES COMPANY	262	TM-LASERTECHNIK	21	WILTING
113	SERVOTRONIC BVBA	290	TNO	223	WZW OPTIC AG
159	SETTELS SAVENIJE	172	TONASCO MALAYSIA SDN BHD	88	XERYON
15	SIGMACONTROL BV	260	TOWA EUROPE BV	259	YAMAZAKI MAZAK NEDERLAND BV
104	SIOUX CCM	187	TRESCAL BV	19	ZEISS
218	SKF BV	236	TSD TOOLING SPECIALIST DERKSEN BV	161	ZME FIJNMECHANISCH ATELIER BV
74	SMARACT GMBH	231	UCM AG		
166	SMC	228	UNITED SPRINGS BV		

INNOVATIONS ON DISPLAY

attocube (stand number 127)
WAVE, new measurement software for IDS3010

The IDS3010 – a compact, ultra-precise and high-bandwidth interferometric displacement sensor – is now available with a software package for real-time data analysis and processing. The new measurement software WAVE enables fast and easy data acquisition, evaluation and reporting. WAVE offers an intuitive user interface and features such as zooming, pausing, and a live Fast-Fourier-Transformation. The export of measurement data to CSV-files enables post-processing in software tools such as Microsoft Excel, Matlab, or Origin. The software package is optionally available for all IDS3010 devices and makes the sensor the ideal tool for a plethora of applications ranging from high-frequency vibration measurements, to machine calibration, and position control. ■

WWW.ATTOCUBE.COM

Capable (stand number 278)
Specialty cables

Capable develops customer-specific specialty cables and connectors as well as systems for a broad diversity of applications in high-tech environments. Capable's cleanroom (NEN-EN-ISO 14644 class 6) makes it possible to improve and grow knowledge and further develop creative (micro- and nano-sized) cable and assembly solutions especially in the medical, semi-conductor, space & defence segments. Also, Capable is AS9100, ISO9001, ISO14001, IPC and ECSS certified. ■

WWW.CAPABLE.NL

Gentec Electro-Optics (Te Lintelo Systems, stand number 95)
BLU, the first wireless laser power meter series

The new BLU All-in-One detectors combine a detector and a meter with Bluetooth connectivity in one convenient product. The small but powerful meter of the BLU Series presents a Bluetooth connection for displaying the results on a mobile device with the Gentec-EO BLU app available for both iOS and Android systems, or on a PC using the included Bluetooth receptor.

Each detector of the All-in-One BLU Series offers Gentec's familiar performance in the mW to kW range. With wireless laser power meters, it is now possible to measure laser power in enclosures and hard-to-reach places. The BLU series makes laboratories and production floors safer by allowing the operators to be farther from the detector while making measurements (up to 30 m, depending on the environment and barriers), and with less cables in the workspace. They are also useful tools for field service technicians who will take advantage of the integrated monitor, thus carrying less instruments. ■

WWW.GENTEC-EO.COM

Connect 2 Cleanrooms (stand number 93)

Contamination Control Considerations for Vacuum Technologies

Vacuum technology specialist, Pfeiffer Vacuum, manage contamination risks with an ISO Class 7 Connect 2 Cleanrooms modular cleanroom, to assure customers that the vacuum technology produced is ultra-clean and therefore will operate at optimal efficiency. As the state of gas and particle density is so important to a vacuum's effectiveness, maintenance on critical vacuum components is performed inside the cleanroom to reduce the risk of contamination. Pfeiffer Vacuum also uses the cleanroom to pack its vacuum components, so end-users can transfer its products directly into their cleanroom.

The modular cleanroom uses HEPA filtration, which is 99.99% efficient at 0.3 μm, to meet the air cleanliness requirements designated by cleanroom standard ISO 14644-1:2015, Class 7. Pfeiffer Vacuum allocated an enclosed room to locate its cleanroom, so Connect 2 Cleanrooms designed a cleanroom of softwall construction to maximise on the space available and allow for ambient light to filter through. This is enhanced by cleanroom lighting at appropriate levels for operational tasks that require a high perception of detail, to improve task accuracy and operator comfort.

As the cleanroom was pre-engineered for an efficient installation on site, the cleanroom installation and commissioning was completed in just a few days, so there was no disruption to Pfeiffer Vacuum on daily work. A modular cleanroom facility was considered to be a lasting investment, as it would be able to be relocated if required by the business.

As well as airborne particulate, there are a number of additional contamination risks during vacuum pump maintenance, including residues from essential lubricants, environmental contaminants resulting from the application and process, and operator contamination from servicing personnel. For this reason, a cleanroom should be part of a larger contamination control strategy. Other considerations should include environmental monitoring and cleanroom operational protocols, such as cleaning and gowning. ■

WWW.CONNECT2CLEANROOMS.NL
WWW.CLEANROOMSHOP.COM

PM (stand number 33)

New compact series of precision linear guides RNG

The new series of linear guides with limited stroke has been developed for smaller build spaces, with special attention devoted to the optimisation of running contact surface and roller geometry. Where up to now for a 6 mm roller the mounting dimensions were 31x15 mm, the new straight guiding has become 25x12 mm. The load capacity has risen a factor three to four, up to a C_{dyn} of 28,240 N. Compared with the classic linear guide, the engineer can choose a smaller and lighter type of linear guide without compromising on the specifications.

The higher-density roller bodies together with the small diameter and the long contact area between the roller and running surface also provide higher stiffness and smooth running characteristics. As a result, higher placement precision can be achieved with higher accelerations. The RNG linear guide requires a minimum amount of lubrication and maintenance for smooth and reliable operation.

Features of the new RNG series:

- downsizing with lifetime extension;
- less sensitive to impact loads;
- minimum three times longer lifetime in existing machines;
- lower weight;
- in addition to steel also stainless steel options, for use in a cleanroom or vacuum application;
- the guides can be (in retrofit) provided with anti-cage-creep technology.

WWW.PM.NL

Precision Micro (stand number 11)

Titanium Etching

Titanium is often the go-to material in the aerospace, electronics and medical sectors because of its superior strength-to-weight ratio, corrosion resistance, extensive temperature range and low thermal expansion coefficients. These attributes make it challenging to machine with conventional sheet metal working, and its corrosion resistance makes it impossible to etch with standard etch-chemistries.

Precision Micro's titanium etching service comes with all the existing benefits of photo etching, producing burr- and stress-free parts with clean profiles and no heat-affected zones. The process is fast and economical with lead-times measured in days not weeks, and it is precise down to the most exacting levels of accuracy even on the most complex of parts. Digital photo-tooling – which is low-cost and quick to produce – means set-up costs are minimal and design engineers can vary the size and shape of plate features without additional cost or hugely increased lead times.

Precision Micro will be focusing on the advantages of photo-etched titanium for heat exchanger plates used in wafer fabrication as companies move away from the use of stainless steel cold plates. Complex, bipolar flow fields can be etched to 0.025 mm, and with accuracy to ±0.025 mm. Precision Micro also offers a number of added-value plate heat-exchanger technologies such as diffusion bonding, which allows complex cooling channels to be incorporated into heat exchangers at a fraction of the price of laser drilling. ■

WWW.PRECISIONMICRO.CO.UK

SIOS (Te Lintelo Systems, stand number 95)

SP-NG interferometers

The new generation of single-beam measuring systems for length and vibration are available as stand-alone or OEM system. The basis of the new device family is a unified sensor head equipped as standard with a PSD unit for a quick and easy adjustment. To meet industrial conditions, the housing was designed splash-proof and the sensitive fiber cable can be protected by a cable conduit. The interferometers of the SP-NG series are easy to use and include several options for minimising alignment errors.

The measuring range of the basic unit is 5 m and guarantees a resolution of ±20 pm. A small ball reflector, which allows measurement at tilt up to +/–12.5 °, can be conveniently attached to the test object by means of screw or magnetic fastening.
For special applications other devices of the same equipment line are available, such as a long-range interferometer and various vibrometers. In addition, a further attachment allows the 90° beam deflection in four spatial directions. The new interferometer system is also predestined for use as a mounting system for OEM applications. A specially developed attachment ensures an extremely long-term stable alignment of the sensor head and saves the otherwise necessary adjustment mount. ■

WWW.SIOS.DE

Sentech (stand number 144)

Eddylab TX series

Sentech, the sensor integrators, now offer the TX series from eddylab. Eddy-current sensors detect the distance or the change to metal objects without contact, dynamically and extremely accurately. The TX electronics which are specially adapted to the respective sensor calculate an analogue output signal proportional to the distance. In addition, there is a USB and CAN interface for reading the data. The eddylab software is the perfect complement to the TX series with its three functional areas (oscilloscope, FFT analysis, datalogger). ■

WWW.SENTECH.NL

FUTURE-PROOFING OF CLEANING PROCESSES

The cleaning of industrial parts is now widely acknowledged as a key value-adding step in the overall production chain. But trends such as Industry 4.0, miniaturisation, electromobility and lightweight construction are posing new challenges for the cleaning of industrial parts and surfaces.

DORIS SCHULZ

In many sectors of modern industry the cleaning of parts and components is essential for preventing quality issues further downstream – e.g., at stages such as coating, adhesive bonding, welding, tempering, and assembly – as well as for the proper functioning of the finished product. The cleaning of industrial parts and surfaces has thus gained the recognition as a value-adding step in manufacturing chains, and a major factor in staying competitive.

Fresh challenges

In many industries, the main emphasis after machining and forming processes used to be on the removal of particulate contaminants using wet chemical cleaning methods. The removal of film-type contaminants has been a priority, notably when preparing parts and surfaces for coating, welding, tempering or adhesive bonding. The need for these cleaning steps is unlikely to change in the future.

However, the trends are posing fresh challenges for the cleaning of parts. One example is the trend towards ever smaller and more complex parts and components expected to perform better and last longer. Other trends, such as shorter product lifecycles, smaller production runs (including one-offs), the use of new materials and combinations thereof (typically in lightweight construction), and new production processes, all have a direct impact on parts cleaning. Not to mention major technical developments such as electromobility, autonomous driving, and the reconfiguration of production processes in line with Industry 4.0.

Adaptability

Wet chemical cleaning will undoubtedly remain the most common technology used. But in order to be prepared for changing market needs and shifting technical demands, the flexibility and future viability of parts and surface treatment facilities is becoming more and more important. The parts cleaning industry is already anticipating emerging needs by designing plants with built-in adaptability to handle different types of parts, different standards of cleanliness and alternative cleaning methods.

This means not only installing more efficient ultrasound systems, pressure pumps and filtration systems, but also incorporating technical developments that enable plant operators to adjust the cleaning parameters to match the specific size and geometry of the parts passing through the system. The ability to quickly and easily swap out cleaning tools such as spray units is one such development, along with the separation of cleaning and drying operations in the case of water-based cleaning.

Fine and ultra-fine cleaning

The requirement for components meeting ever higher standards of cleanliness is coming on the one hand from such established high-tech fields as semiconductors, micro-technology and electronics. The task here is to remove surface contaminants in the form of particulates and films, as well as water stains and discolouration, while biological and ionic contaminants are also an issue in some fields. On the other hand, new types of components such as those used in the electrification of drivetrains or in driverless cars are posing new challenges for the parts cleaning industry. Such components come with a range of exacting performance requirements: the ability to conduct electricity and support continuous current flow, good coatability, and, in the case of optical sensors, 100% guaranteed functionality.

To remove particulates and surface films and achieve the requisite degree of cleanliness, manufacturers are increasingly turning to fine and ultra-fine cleaning processes (Figure 1). Alongside the basic design and configuration of the cleaning plant (number of treatment stations and drying facilities) plus appropriate process

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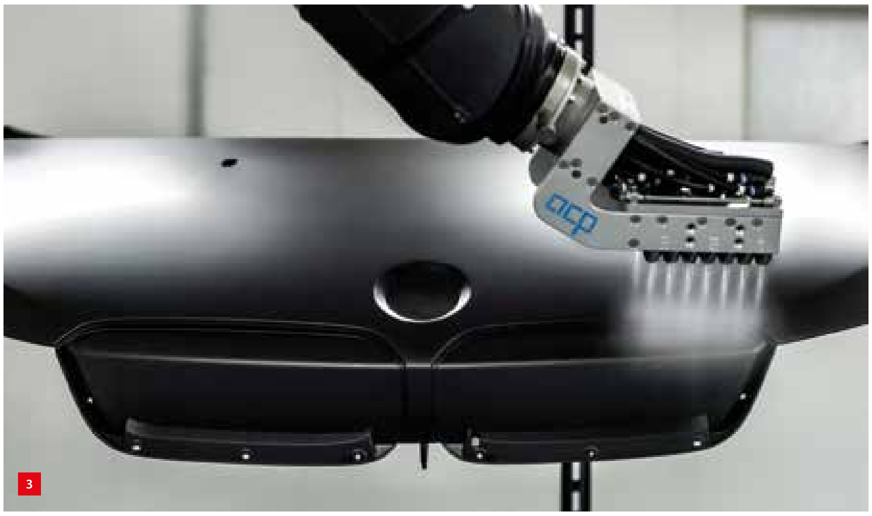
www.schulzpressetext.de
www.parts2clean.com

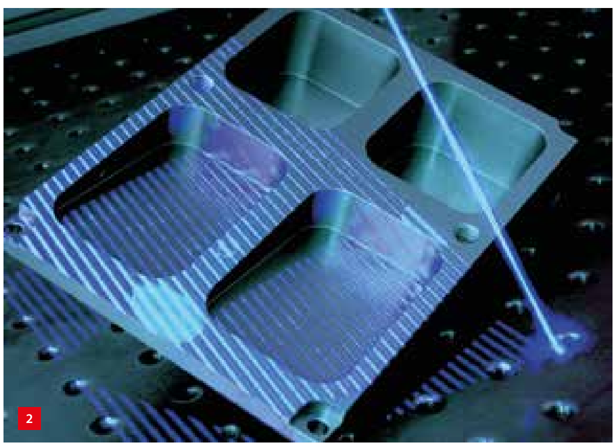


technology (e.g., multifrequency ultrasound), cleaning chemistry and process design, other technical aspects also need to be considered. These include such things as flow optimization, parts carriers, piping, conveyor automation and air management.

Integrated processes

The trend towards intelligent, networked production processes – enabling manufacturers to achieve greater productivity, improved product quality and flexibility while at the same time reducing their costs – is also driving changes in industrial parts cleaning. Already available are fully automated inline plant solutions that can clean and dry bulk goods such as screws, and then transport them onwards to the next processing stage. The latest intelligent generators for use in ultrasonic cleaning can now configure themselves and then monitor and optimise their own operation. This means, for example, that the optimum operating frequency can be automatically determined and set before the ultrasonic pulse is triggered.

The continuous monitoring and logging of plant and process parameters in wet chemical cleaning plants is now a common feature. Plants can be equipped with sophisticated instrumentation for the continuous inline monitoring and control/adjustment of cleaning baths. These systems not only permit accurate documentation of operating parameters during cleaning, but can also be used to inject additional cleaning agent into the bath as required, and the process is fully automated, needing no intervention by the machine operator. Initial solutions for the inline monitoring of cleaning results are also now available; these typically use fluorescence measurement technology to check for the presence of any film residue (Figure 2).



Dry cleaning

Selective dry cleaning of functional surfaces and designated areas of components prior to adhesive bonding, sealing or laser welding, as well as pre-assembled parts, using CO_2 snow blasting (Figure 3), laser cleaning or plasma cleaning techniques, has hitherto been something of a niche specialty. However, the selective cleaning of functional surfaces is set to become more mainstream in the future, given that a single workpiece can present a range of different cleaning challenges, depending on the degree of surface cleanliness required for selected areas destined for further processing, or on the use to which the component will be put. The fact that inline-capable processes are easily automated has also helped to drive this trend.

Now becoming much more widespread, lightweight construction – which typically uses aluminum, composites and new combinations of materials – is another area where dry cleaning processes have become increasingly important. One example is the use of CO_2 snow blasting by the manufacturers of electric cars to clean plastic body panels and mouldings prior to painting. ■

1 *To remove particulates and surface films and achieve the high degree of cleanliness that many components require, manufacturers are turning increasingly to fine and ultra-fine cleaning processes. (Source: Ecoclean / UCM)*

2 *Inline measurement of cleanliness using fluorescence measurement technology to check for the presence of any film residue. (Source: Fraunhofer-IPM, Member of Fraunhofer Cleaning Technology Alliance)*

3 *One use of CO_2 snow blasting is to clean plastic body components for electric cars prior to painting. (Source: acp – advanced clean production)*

'NON-TRADITIONAL' EDM PROCESS PERFECTLY FITTING IN THE DIGITAL AGE

Near the end of the last millennium high-speed milling almost brought EDM (electrical/electronic discharge machining), at that time still an unconventional machining technology, to a standstill. Now, some 20 years later, the situation is quite the opposite: advanced electronically-boosted spark erosion is blooming again, although in different settings. An overview of the state of the art in EDM.

JAN WIJERS

R&D on EDM, and developments in ICT and electronics have spurred massive progress, up to digitised, high-performance 'spiked' generators, powerful CNC machines with tablet-style HMIs and far more 'intelligent' technology. Miniaturisation, tighter tolerances and top-class engineering have brought about new high-end applications based purely on clear-cut advantages of each configuration of this contactless precision technique. For example, fine injector hole drilling, accurately cutting of highly loaded 'fir tree' interfaces in turbines, top-design flexures and delicate removal of support structures at the end of additive manufacturing cycles. On top of this, leading EDM experts and researchers point out that there still is space for quite some improvement and new, innovative application fields.

Spark erosion in retrospect

As the necessity increased up to and around 1940-1950 to machine ultra-hard and brittle materials, electrical discharge machining (EDM) was developed. Traditional machining in itself depends for its chipping action on at least one factor higher hardness and wear resistance of the tool versus the product to be machined. Lazarenko & Lazarenko [1], Zolotych [2] and later on Mironov deduced the – currently still largely accepted – thermophysical theory that is the best fit for the physical phenomena that were observed.

Nowadays – almost 70 years after the very first positive effects of the EDM process emerged – not a single technician or academic seems to feel the urge (or manages to secure research funding) to fully unravel the actual background of the fundamentals within spark erosion, as the renowned international specialist Bernd Schumacher observed a few months ago. At the same time – if ever – "they now have at their disposal the measuring instruments, sophisticated sensors, ultra-high-speed cameras, software for modelling algorithms and powerful computing capacity to quantify and qualify this special thermophysical process", he said.

Machine orders are on the rise in all sections of spark erosion, although the relative position of the sections did completely reverse. Wire-erosion and EDM (micro-)drilling are in the lead, with diesinking machine tools trailing behind more, although larger, highly stable types of the latter are nowadays again in demand. More and more modular machine tool building is preferred with identical platforms wherever possible, both for the main mechanical components, the motion drives, the CNC control and the EDM pulse generator, and a number of automation options in the periphery.

The basic, electrically conductive material structure of the workpiece to be eroded is still slightly sensitive to becoming heat-affected, although the so-called re-cast layer of advanced power supplies has been reduced substantially (≤ 1 μm) – in the quest for total surface integrity. With the aid of latest-generation machine tools, advanced digital generators, sensing devices and software controls, the negative effect of EDM – heat-affected zones, residual stresses, depth variations and the hardness gradient – is reduced to an absolute minimum.

Whether the actual metallurgical integrity on a submicron scale is acceptable depends largely on the conditions in actual use. In certain automobile applications parts subjected to EDM are heated constantly to a temperature level identical to the recommended heat treatment for post-machining. Within aerospace, components are currently

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heat-treated in standard sequences – and/or brazed – at elevated temperatures after which the degree of degeneration in machined structures is very hard to ascertain.

Revival factors

Aside from the inherent benefits of this contactless operating technique (Table 1), a couple of circumstances evoked this remarkable EDM revival. First of all, an increasing number of jobs are started nowadays from so-called 'near-net-shape' blanks. This means that the volume that is to be 'subtracted' has been drastically reduced, so that fine trimming is the major task, instead of consecutively roughing and finishing a particular EDM job.

As a fully electr(on)ically-based machining process, EDM immediately mastered – at a much earlier stage than other machining techniques – the art of using numerical control in actual practice to the full. This includes features such as:

- Adoption of standard electrode tools as a contactless, very precise, audible edge finder – based on 'soft' sparking over the spark gap for so-called 'touch detection'– in setting up, aligning and other very precise measuring cycles (Figure 1).
- Providing wide sets of technology parameters on board the CNC memory.
- 'Open' operator access controls.
- Automatically – CAM- or application-specific – real-time controlling and self-adjusting the progress during material removal.

High-strength and high-heat-resistive materials – that are impossible or extremely difficult to machine in a traditional way – are at the top of the pyramid in EDM applications. Additionally, specific design-for-manufacturing for EDM boosted machining by sparks, especially in high-end micro and precision engineering.

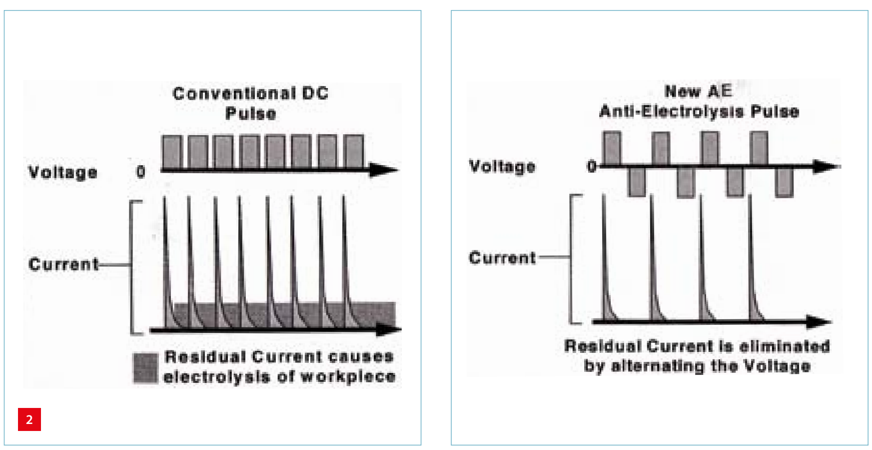
Table 1. Advantages and disadvantages of the EDM process.

Advantages	Disadvantages
Machining in final hardness & metallurgical structure	Conductive materials only (down to a threshold value)
Free of process forces and physical contact	Tools required
100% predictable & reproducible technology	Wear
Autonomous process sequences	Thermal effects
Process fully accepted in industry	Low material removal rate
High accuracy, ± 1 µm	
Finest roughness, $R_a \leq 0.1$ µm	
Burr-free	
Fit for automation	

Digital electronics

Seen from the electrical side, the generators of that early period worked in an analogue style. Rather bulky electronic components and sub-assemblies were assembled onto large PCBs. Generator, motion control and CNC for the most part filled a complete stand-alone, continuously aerated cabinet, that was to a high degree shielded mechanically, thermally and electromagnetically (EM interference) from the machine tool itself. As a consequence long power cables encapsulated in reinforced plastic shielding were used in an entangling harness to make the interconnections, resulting in a loss of energy and a rise in temperature. After years in action the power lines stiffened and thus hampered certain mechanical functions, for example. In addition, the pulses had a rather primitive basic configuration.

Digitally, the pulse generation – especially time and form – and control is in general far better defined, controlled and documented than in the former analogue predecessors, and of a more constant quality. With modern bi-polar power supplies, oxidation and pitting is no longer a problem, even after extended EDM cycles submerged in deionised water (Figure 2). Modern, downsized electronic devices such as generators, motion drives and servo controls also need less energy, which reduces the necessity for cooling.



1 *Direct measuring, aligning and calibrating with a wire electrode (Mitsubishi). See the colour scheme in the upper right part of the screenshot.*

2 *Conventional DC versus Anti-Electrolysis digital pulses. ; see text for further explanation. (Source : "VM 120 Vonkerosie 2008, theorie en praktijk", FME Working group (chaired by ing. J.L.C. Wijers))*

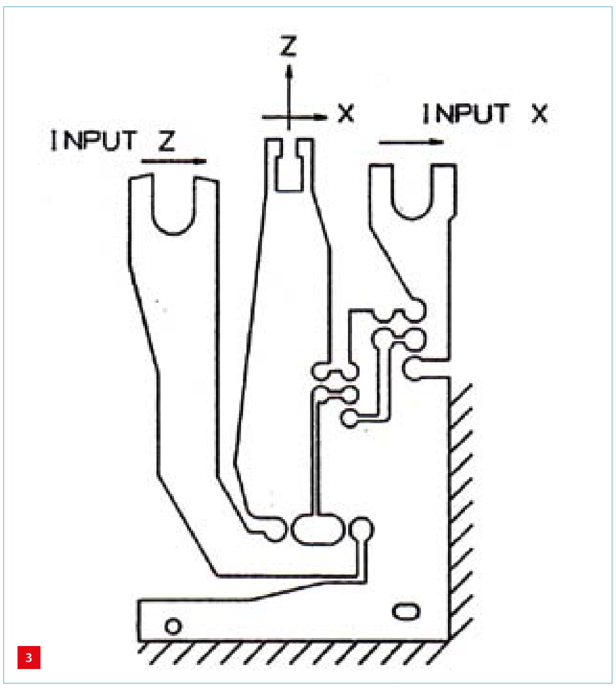
Nowadays, these compact generators are mounted – with short leads – as close as possible to the electrode, whether on a diesinking or a wire type. On some new wire models the generator sits vertically on the 'dry' backside of the work tank. In micro-EDM for example, the Swiss company Sarix even builds the pulse generator inside the ram-head of their one-of-a-kind compact EDM line.

What's more, 'modern' pulses – still to be adapted to the actual application – are of a more advanced, 'spiked' style: much sharper and, most importantly, shorter. Similar to other modern machining processes – such as ultra-short-pulsed lasers – power is of less importance than the pulse time. Transferring sufficient energy in a shorter on-time helps to reduce the direct heat influx. Increasing the repetition rate of these pulse trains considerably at the same time, even results in a higher material removal rate (MRR) under certain conditions.

Wire-erosion breaking through

For some time, wire-erosion (W-EDM) has stood for a competitive means of producing micro- and precision parts, demonstrated for example by means of the rapid spreading of integrated flexures and joints combined with piezo-electric nano-drives (Figure 3)

One of the main advantages of using W-EDM in demineralised water is the fact that contouring is effectuated by almost endless, extremely fine, solid or coated metallic wires, with diameters as low as Ø10 μm, but generally in the range between 100-250 μm up to a maximum of 330 μm. Decades ago, it was proven that an oil-based dielectric fluid instead of deionised water improved the geometrical accuracy and structural quality, especially in machining carbides. A reduced spark gap also produced a gain in a stricter process control. The only negative result was a loss in effective pulse energy, directly linked to a somewhat reduced cutting speed. It is also a technology that takes the heat out of EDM by very short pulses and an almost perfect cooling by forced flushing combined with a dielectric bath.



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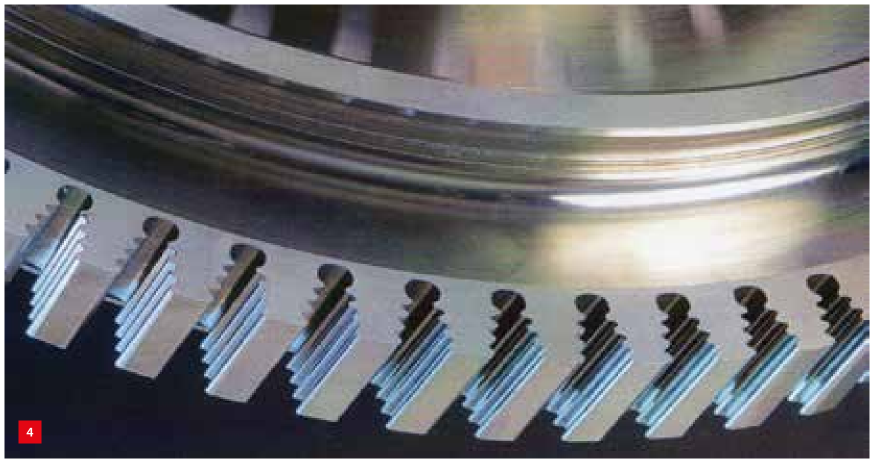
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3 *One of the earliest industrial flex hinges, produced by wire-EDM.*

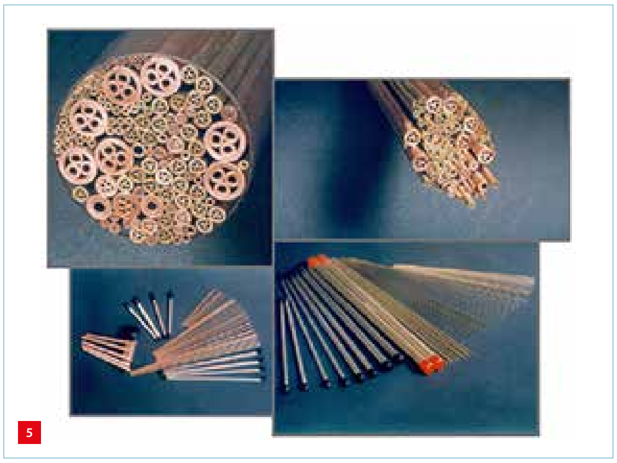
4 *Fir-tree-shaped interface in between turbine wheel and separate blades.*

Recently, a real breakthrough towards general acceptance in aerospace emerged. In gas turbines the interface – a sturdy 'fir tree' fixation (Figure 4) – between separate blades and the wheel disc is loaded by huge centrifugal forces. On both the hub (35-40 per engine) and on the roots of all individual blades (25-150 per wheel) this typically profiled taper has to be machined with a highly repetitive geometrical accuracy and low roughness. Until now broaching is preferred with rather high costs of dedicated tools and long lead times.

Today, dedicated, latest generation W-EDM machines – with a robust mechanical configuration and a swivelling rotary table – offer a more efficient, flexible and low-cost alternative with identical, non-critical thermal effects on sensitive materials, as proven by a series of harsh tests. Traditionally, the servo-controlled feed was based on the mean pulse voltage. Nowadays, the number of effective discharges measured inside the spark gap is used as a means of governing and tracking the progress over the programmed spark-erosive path, a sort of 'follow the pulses'. These data – including the end-results – are also registered statistically in order to comply with strict aerospace traceability. This sort of tops off the best of already highly advanced technology including digitally connected features such as software-based optimisation and simulation with modern tooling.

Self-learning shaping up EDM drilling

Drilling is one of the oldest mechanical operations by mankind. No wonder it has been a common feature in the EDM process right from the start, first purely a sinking mode. Later the drilling speed improved considerably with



5 *Set of special, high-L/D (length-over-diameter ratio), drilling mini-tubes with inner web (for preventing the flexing of a pip with standard pipe-cross section).*

6 *Typical stand-alone standard EDM start-hole drilling machine (Mitsubishi 43z).*

7 *Sophisticated set-up on an industrial multiple-axis EDM-drilling machine (Makino EDBV-8).*

8 *Principle of a self-learning system for EDM. (Source: GFMS)*

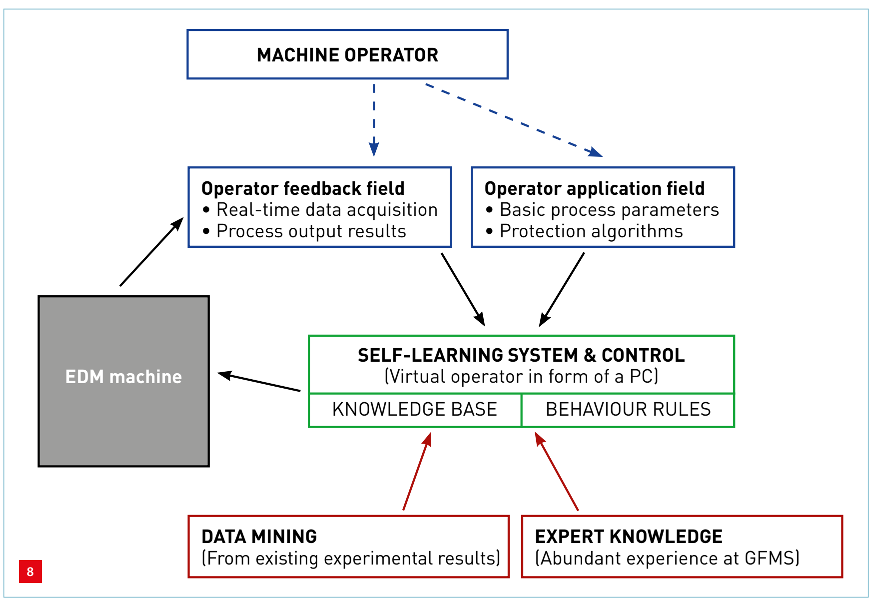
special options such as electrode rotation and high-pressure dielectric. Flushing axially through the so-called coreless tubular electrodes (Figure 5), a sort of stabilising, hydrostatic action in the spark-gap zone around the tip is created.

The fact that W-EDM profiles are generally initiated from pre-drilled starting holes – inside the blank to prevent warping and wire breakage – did give a strong impetus to EDM-drilling (Figure 6). These modern essentials helped to transform the traditional dry-acting (broken) tap-buster into a modern deionised-water-based – sometimes mixed with special additives – or oil-based electrical discharge drilling (EDD) machine tool.

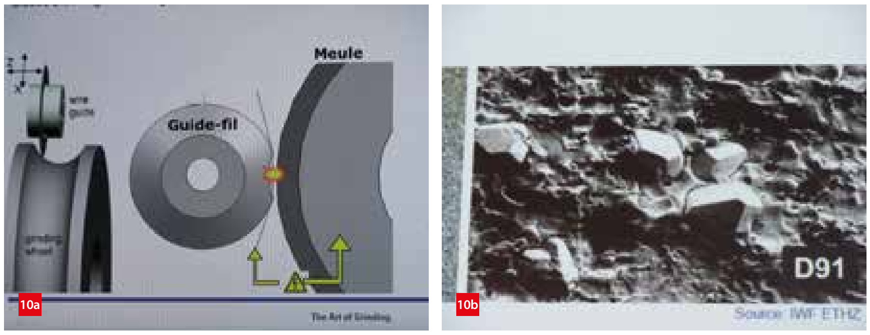
So-called short and 'hard' pulses – high amperage/high voltage – characterise EDD with mini-tubes of Ø0.2-3.0 mm in stand-alone machines. Newest generators, high rotation and inner high-pressure flushing result in extreme speeds and until now unmet MRR. In a number of applications speed is even sacrificed for a sharper run-in/-out edge and improved integrity.

High-efficiency film-cooling in special heat-resistant parts and high-performance components especially in the latest generations of 'high-power/low-fuel' aero, automotive and power devices is increasingly sought. On the basis of the advantages of contactless drilling of very fine diameter ranges over extreme *L/D* ratios – as well as special configurations such as free-shaped fan holes – and the availability of special multi-axis set-ups, with indexing and swivelling motions and automatic guide/electrode-changer, industrial EDD can be found in every turbine manufacturing and refurbishing plant (Figure 7).

Self-learning systems (Figure 8) have been tested in the laboratory and are being introduced in industry. This fairly



'simple' production technique features a reduced number of parameters compared to deep-sinking and W-EDM. Blind holes can already be produced to a given depth by automatically compensating the wear of the electrode.
A huge amount of basic and advanced data already exists, generated during more than 50 years by suppliers, users and laboratories. An enormous expert knowledge base thus already exists, partly supplemented with operator feedback. Without human interaction and input, working with a kind of virtual operator on artificial intelligence and self-learning algorithms, an optimal choice for difficult materials – out of almost infinite possibilities – is guaranteed within the hour, even up to the stage of pre-validation.



10 *Wire-dressing of metal-bonded superabrasive wheels.*
(a) Principle.
(b) Structure of wire-dressed metal-bonded superabrasive matrix.

Diesinking back on track

In automotive, power generation, aerospace and die & mould branches, modern diesinking machines are still active – with all their additional options – although in reduced numbers. More than the other EDM variants, diesinking is converting into fully-automated – or more precisely – closed-loop manufacturing (CLM).

This CLM possibility was demonstrated by the Alicona company on a Makino EDAF2, working in perfect harmony with a HiRes optical measuring head for real-time data-acquisition. The diesinker was equipped with an additional W-axis – parallel to the main vertical Z-axis – on which the Austrian company fixed one of its continuously variable focus options (Figure 9). Tediously unclamping and transferring the job in a traditional manner on its holder over to a coordinate measuring machine, then measuring and comparing it to the CAD-file, automatically computing the defaults, compensating and correcting the process parameters and re-clamping it, means a considerable loss in time, money and quality.

9 *Closed-loop diesinking machine (Makino EDAF2).*

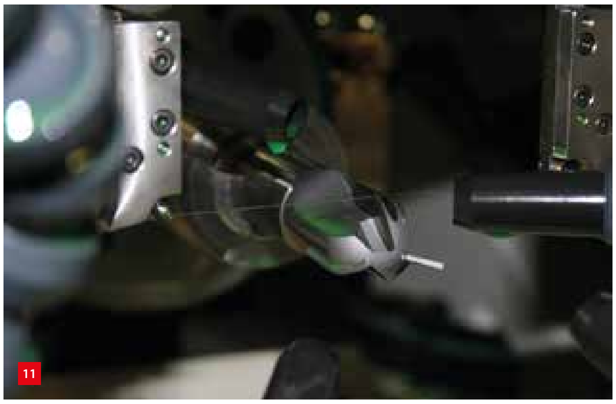
This new set-up functions stably while measuring in-process – as proven in workshop conditions – with direct part-related feedback to both the CNC control and generator, and inline autonomous correction.
In modern gas turbines lots of fragile components – such as specific honeycomb-like seals and different high-aspect-ratio features – are integrated. For their realisation very delicate, force-free machining operations have to be performed with high repeatability, which absolutely cannot be generated at the moment other than by means of advanced diesinking EDM.

Competing on special applications

For an outsider the machining scene is becoming very diffuse because of the enormous mix offered. Applying fully-automated wire-erosion as an industrial dressing solution for metal-bonded superabrasive wheels with ultrafine abrasive grains has left the realms of the laboratory (Figure 10). Nowadays, the Swiss Studer company supplies a professional W-Dress option at its precision grinding centres. This compact patented unit is meant for profiling sharpest contour elements in the abrasive tool at hand, plus obtaining the best topology for grinding.

On the other hand, the Japanese machine tool builder Mitsubishi Electric released an add-on to its MV series with tubular linear drives on all axes and an optional ITS rotary/index unit. A stand-alone FA10S fully-automatic special version has also been developed for external conditioning, comprising dressing all kinds of grinding wheels by autonomously correcting the form, opening up and resharpening the active outer layer.

Laser beam machining (LBM), EDM – both wire-cutting and spark-erosive grinding with a plain or profiled disc electrode – and abrasive grinding actually compete fiercely in the PCD and CBN cutting tool field. Several machine tool builders, such as Vollmer (Figure 11), even have all three versions in their spectrum. Sharp edges for rapid chip breaking, smooth surfaces and more or less freeform



11 *Vollmer Exactaform EDM-profiling tool.*

contouring are the key to the EDM success – even on hybrid materials.

The quickly expanding trend into e-mobility brings W-EDM back into the spotlight for accuracy, with highest surface quality and flexibility, prototyping parts for example in copper (alloys) and producing the necessary stamping tools for the latest types of automotive power drives. Dedicated punches and dies for serial production can be cut specifically for this new generation of electric motors.

Automation integral part

In production, a lower price per part is imminent in all three main EDM sections: diesinking, wire-erosion and drilling. In order to make the most out of productivity, flexibility and effective up-time, flexible automation constitutes a key item. An important means of reaching that goal today – especially in so-called 'lights-out' periods (i.e., in unmanned operation) – is the changing of electrodes, measuring probes as well as parts and pallets in-process.

Only one company is offering the unique and proven 'twin wire' option for automatically changing over to the best suited and most profitable wire electrode for the task during a particular cutting operation. GFMS has fine-tuned its threading capacity as well as redesigned the compact double-wire head for combining different types and diameters – plus guides (Figure 12). Cutting cycles can be executed quickly with a 'big'-diameter (Ø100 µm, Ø250 µm and Ø330 µm) standard or coated wire in a roughing cut. Without human intervention, switching over is feasible with this third-generation automatic wire changer to smaller types (Ø75 µm down to Ø10-20 µm). These are perfect as trim cut in fine finishing of detailed geometry elements and for the smallest radii (Figure 13).

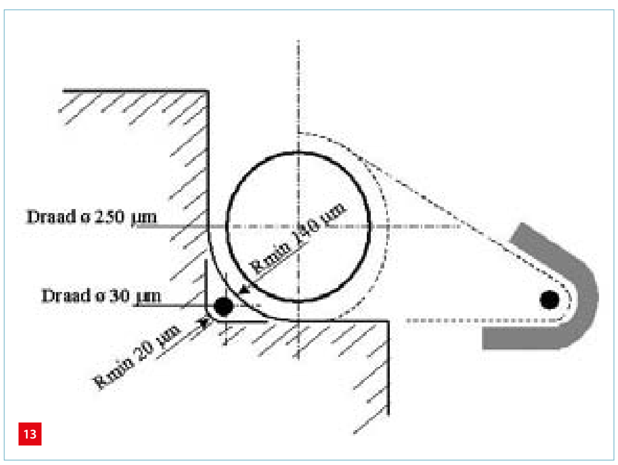
Drilling – especially with tight tolerances and dimensions – in production means that guides and small copper, brass or tungsten copper pipes must be exchanged regularly, whether or not fixed in their clamping chuck. Either worn-out electrodes enforce tool switching, or taking up a different job or using another diameter. More or less new is that professional types feature up to five – including the drilling head – installed multiple advanced guide mechanisms when using extremely long drilling tubes with a spectacular length-over-diameter ratio (normally 100, up to 300 or even 400), in some cases with swivelling axis, either in the head or on the side of the part and clamping fixture.

In the beginning, keeping the delicate, easy-to-bend mini-tubes perfectly straight, clean on the inside and outside and without burr, was an operator's nightmare. Nowadays, some technologists on the contrary address the inherent flexibility in guiding them in a forced manner over a specific curvature or at an angle to obtain bores in awkward situations inside a job.

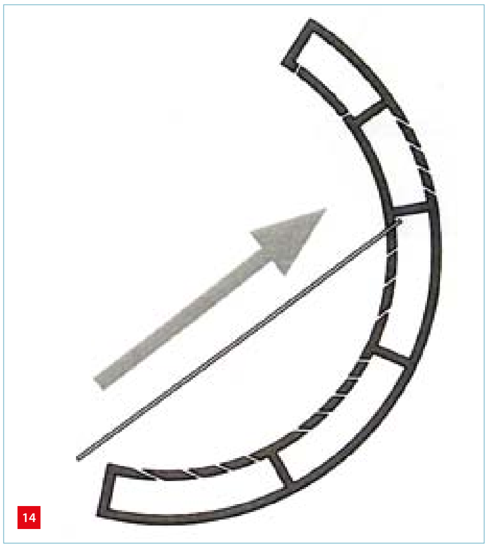
Breaking through the wall can now be detected by a sudden changeover to unstable conditions in the gap, whereupon the controller reacts in split seconds by reducing the settings progressively, preventing unwanted back-striking up the inside of the bore or perforating the opposite wall (Figure 14).

A number of frontrunners in industry are running their production in fully-automated and integrated cells – mostly a universal set-up coupling freestanding EDM-machines

12 *Automation in changing on two sides: parts and tools/wires (GFMS).*



13 *Geometrical consequences of choosing a smaller or bigger diameter wire; "Draad" = Wire. (Source: WISE2000)*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14 *Illustration showing the necessity of breakthrough detection (Heun).*

15 *Improved 3D structure (lower left) compared to traditional EDM-texture (GFMS).*

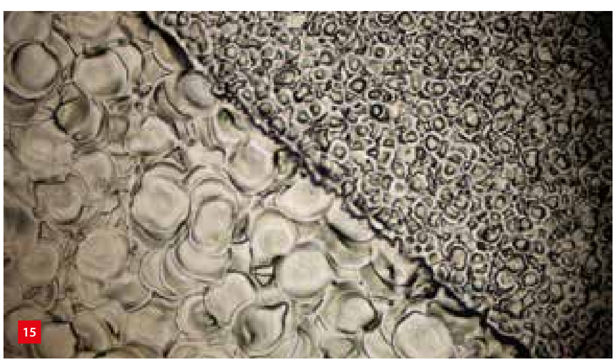
16 *New Sarix Sx-Cobot Micro-EDM with new Pulsar generator and collaborative robot inside*

and (5-axis) milling centres to washing, cleaning and drying stations up to final measuring as part of qualification.

What's in the future?

More so than with any other machining technology, EDM is showing that it fits perfectly – as a fully digital, electronic solution – within the now propagated seamless connectivity of the e- or i-Factory of the Future. For example, EDM-texturing and -structuring could be blossoming into a bright new future.
Increasingly the functional issue(s) of a machined surface are of greater interest than the pure R_a value in its two dimensions. It is well-known that technologists in spark-erosion shops used to improve crater-shaped workpiece surfaces with special A(gie)- or C(harmilles)-settings towards one of the roughness-ruler-defined textures or even a glossy finish. (Micro-)textures are used to obtain improved decorative looks or a cosmetic cover-up in particular for 'poor-man's plastic' looks, or to get rid of local glossy and mini-defects.

Quite inspiring is that functional changes might be expected on top of the improved final quality of EDM sequences. In that respect, GFMS recently showed the quality of their modified 3-Dimensional Structuring (Figure 15). By a purposeful change in the surface pattern of a mould – the EDM process producing shallower craters, more rounded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on top, without actual loss of machining time – the functionality during injection moulding has improved. This has to do with reduction of the expelling forces and the tool maintenance (especially cleaning).

The inherent contactless character of spark erosion is also associated with additive manufacturing (AM). W-EDM is already sought for as a meticulous and precise method for removing metallic support structures. At the same time, at least one powder producer reports as a secondary effect that the remaining white layer in metal-AM parts is more readily removed than in conventionally produced alloys. From another point of view this kind of force-free post-processing – aside from hydraulic process-induced forces – might be advantageous because it will be easy to hold intricate AM pieces with an optimal topological design during contactless EDM processes. On these fragile freeforms, workpiece holding can be practised at such a low force level that excessive clamping is no longer a source of defects.

A similar situation exists in micro-EDM processes during the machining of small pockets, holes and cutting. A sample of the progress that has been made was unveiled at the EMO 2017 fair last September in Hannover, Germany. Certainly leading in the field was the brand new Sarix SX model with Pulsar generator and – most importantly of all – with a collaborative robot inside for performing all the handling – under wireless control using RFID scanning – of all items such as machining, EDM and fibre laser head, workpieces, electrodes, guides and touch probes to improve productivity and quality (Figure 16).
All in all, EDM is without doubt on its way to a 'first time right' spark(l)ing future with zero defects. ■

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ECP² COURSE CALENDAR

COURSE (content partner)	ECP² points	Provider	Starting date (location, if not Eindhoven, NL)
FOUNDATION			
Mechatronics System Design - part 1 (MA)	5	HTI	to be planned (Q1/Q2 2018)
Mechatronics System Design - part 2 (MA)	5	HTI	to be planned (Q3/Q4 2018)
Design Principles	3	MC	7 March 2018
System Architecting (S&SA)	5	HTI	30 October 2017
Design Principles Basic (MA)	5	HTI	to be planned (Q2 2018)
Motion Control Tuning (MA)	6	HTI	15 November 2017
ADVANCED			
Metrology and Calibration of Mechatronic Systems (MA)	3	HTI	7 November 2017
Actuation and Power Electronics (MA)	3	HTI	14 November 2017
Thermal Effects in Mechatronic Systems (MA)	3	HTI	19 March 2018
Summer school Opto-Mechatronics (DSPE/MA)	5	HTI	-
Dynamics and Modelling (MA)	3	HTI	27 november 2017
Manufacturability	5	LiS	30 October 2017 (Leiden, NL)
Green Belt Design for Six Sigma	4	HI	to be planned
RF1 Life Data Analysis and Reliability Testing	3	HI	6 November 2017
SPECIFIC			
Applied Optics (T2Prof)	6.5	HTI	31 October 2017
Applied Optics	6.5	MC	22 February 2018
Machine Vision for Mechatronic Systems (MA)	2	HTI	to be planned (Q2/Q3 2018)
Electronics for Non-Electronic Engineers – Basics Electricity and Analog Electronics (T2Prof)	6	HTI	to be planned (Q3 2018)
Electronics for Non-Electronic Engineers – Basics Digital Electronics (T2Prof)	4	HTI	to be planned (Q1 2019)
Modern Optics for Optical Designers (T2Prof)	10	HTI	19 January 2018
Tribology	4	MC	31 October 2017 (Utrecht, NL) 6 March 2018
Basics & Design Principles for Ultra-Clean Vacuum (MA)	4	HTI	5 December 2017
Experimental Techniques in Mechatronics (MA)	3	HTI	to be planned (Q2 2018)
Advanced Motion Control (MA)	5	HTI	6 November 2017
Advanced Feedforward Control (MA)	2	HTI	21 March 2018
Advanced Mechatronic System Design (MA)	6	HTI	to be planned (Q3/Q4 2018)
Finite Element Method	5	ENG	in-company
Design for Manufacturing – Design Decision Method	3	SCHOUT	in-company
Precision Engineering Industrial Short Course	5	CRANF. UNI.	to be planned (Cranfield, UK)

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The European Certified Precision Engineering Course Program (ECP²) has been developed to meet the demands in the market for continuous professional development and training of post-academic engineers (B.Sc. or M.Sc. with 2-10 years of work experience) within the fields of precision engineering and nanotechnology. They can earn certification points by following selected courses. Once participants have earned a total of 45 points, they will be certified. The ECP² certificate is an industrial standard for professional recognition and acknowledgement of precision engineering-related knowledge and skills, and allows the use of the ECP² title.

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  WWW.T2PROF.NL
- Systems & Software Academy (S&SA)

UPCOMING **EVENTS**

8-9 November 2017, Glasgow (UK)
Special Interest Group Meeting Micro/Nano Manufacturing
The focus will be on novel methodological developments in micro- and nano-scale manufacturing, including process optimisation, quality assurance approaches and metrology.

WWW.EUSPEN.EU

15-16 November 2017, Veldhoven (NL)
Precision Fair 2017
Seventeenth edition of the Benelux premier trade fair and conference on precision engineering, organised by Mikrocentrum.
See the preview on page 39 ff.

WWW.PRECISIEBEURS.NL

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23 November 2017, Utrecht (NL)
Dutch Industrial Suppliers & Customer Awards 2017
Event organised by Link Magazine, with awards for best knowledge supplier and best logistics supplier, and the Best Customer Award.

WWW.LINKMAGAZINE.NL

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30 November 2017, Eindhoven (NL)
Robotics Technology Symposium
Event organised by the High Tech Systems Center at Eindhoven University of Technology (TU/e). Keynotes by professors Maarten Steinbuch (TU/e), Eldert van Henten (Wageningen University & Research) and Stefano Stramigioli (Universtity of Twente).

WWW.TUE.NL/HTSC

12-13 December 2017, Amsterdam (NL)
International MicroNanoConference 2017
Microfluidics, photonics and nano-instrumentation are main topics of this industry- and application-oriented conference, exhibition and demo event.

WWW.MICRONANOCONFERENCE.ORG

13-14 December 2017, Den Bosch (NL)
AgriFoodTech 2017
Second edition of event featuring innovations within the agri and food sectors, such as sensors, drones, autonomous robots, smart farming, big data, vision technology and smart LEDs. The focus is on efficient, effective and sustainable production, in machine design and food processing as well as in the field.

WWW.AGRIFOODTECH.NL

7-8 March 2018, Veldhoven (NL)
RapidPro 2018
The annual event on prototyping, (low-volume) production and product development. An important prototyping and production technology at RapidPro is 3D-printing. Also many other technologies will be comprehensively presented, "from design to manufacturing".

WWW.RAPIDPRO.NL

20-23 March 2018, Utrecht (NL)
ESEF 2018
The largest and most important exhibition in the Benelux area in the field of supply, subcontracting, product development and engineering, showcasing the latest innovations.

WWW.ESEF.NL

21-23 March 2018, Dresden (DE)
Conference on Thermal Issues in Machine Tools
This conference is organised by CRC/TR 96 and euspen (Special Interest Group Thermal Issues), which have been working to solve the conflict between reducing energy consumption and increasing accuracy and productivity in machining since 2011.

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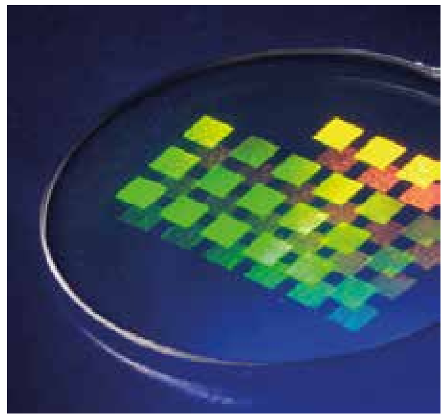
10-11 April 2018, Aachen (DE)
Aachen – Polymer Optics Days 2018
International Conference featuring injection-moulded optics, line production of planar optics and sheets, new materials and applications for plastic optics, light sources and optical systems, and digitalisation of the optics production. Organised by Fraunhofer and ILT, and the Institute of Plastics Processing (IKV) in Industry and the Skilled Crafts at RWTH Aachen University.



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30-31 May 2018, Veldhoven (NL)
Materials 2018,
Trade fair, with exhibition and lecture programme, targeted at product developers, constructors and engineers. The focus is on materials - analyses - surfaces - connections.

WWW.MATERIALS.NL

4-8 June 2018, Venice (IT)
Euspen's 18th International Conference & Exhibition
This event will once again showcase the latest advances in traditional precision engineering fields such as metrology, ultra-precision machining, additive and replication processes, precision mechatronic systems & control and precision cutting processes. Furthermore, new topics will be addressed covering robotics and automation, Industry 4.0 for precision manufacturing and applications of precision engineering in biomedical sciences.

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PRECISION TALENT FLOURISHING IN THE LOWLANDS

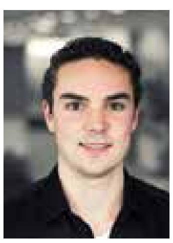
Technical talent, crucial for the future of the Dutch (and Belgian) high-tech industry, is graduating at a high level at universities of technology and applied sciences in the Netherlands and Belgium. This is evidenced by the large number of nominations for the Wim van der Hoek Award. A total of nine nominations were received by the jury for this award, which will be presented in November for the twelfth time at the Precision Fair under the auspices of DSPE.

The second day of the 2017 Precision Fair in Veldhoven, the Netherlands, Thursday 16 November, will feature the presentation of the Wim van der Hoek Award. This award (also known as the Constructors Award) was introduced in 2006 to mark the 80th birthday of the Dutch doyen of design engineering principles, Wim van der Hoek. The objective was, and still is, to promote and stimulate the discipline of mechanical engineering. This award includes a certificate, a trophy produced by the Leiden Instrument Makers School as well as a sum of money (sponsored by the 4TU federation).

Best graduation project

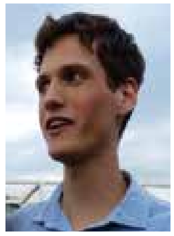
The Constructors Award is presented every year to the person with the best graduation project in the field of design in mechanical engineering at the Dutch universities of technology and applied sciences. Criteria for the assessment of the graduation theses include quality of the design, substantiation and innovativeness, as well as the suitability for use as teaching materials. The jury, under the presidency of DSPE board member Jos Gunsing (MaromeTech), received nine nominations, submitted by the graduation supervisor/professor of the student concerned. A total of two universities of applied sciences and three universities nominated candidates: AVANS Hogeschool Breda, Fontys Hogescholen, KU Leuven (Belgium), TU Delft and TU Eindhoven.

Candidates



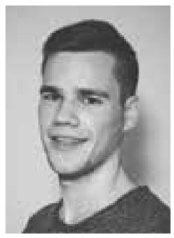
Pieter van Eijkeren (AVANS Hogeschool Breda)

The advantage of allowing plastic deformations during the removal of an offshore facility
"Pieter has worked very autonomously, above higher professional education level. He followed the right courses on his own initiative, resolved setbacks and produced an exceptionally good and clear thesis. His subject, the removal of oil drilling platforms, is highly topical and can give the industrial partner for this project a competitive advantage in the currently 'difficult' offshore industry."



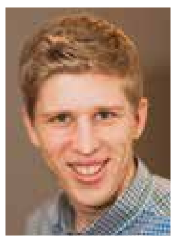
Lars van der Woude (AVANS Hogeschool Breda)

Avans Robotic Hand – A system for dexterous manipulation with a soft touch
"Lars has been working on a three-finger robot hand designed to quickly grab objects with a soft grip. In designing, he followed the 'precision engineering' approach for dynamics and construction principles. He partially succeeded, but this is a special achievement for a bachelor student."



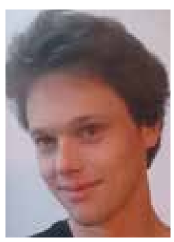
Gijs Bardoel (Fontys Hogescholen)

Collaring Machine – Concept to Prototype of a machine to decrease the production time
"Gijs is a young and ambitious multi-skilled engineer. He had to design a machine and manage its production during his graduation project, which was successfully completed. The machine is running well and the whole design and development process has been very well documented."



Sam Peerlinck (KU Leuven)

Asymmetrisch bewegende cilia voor vloeistofpropulsie bij lage Reynoldsgetallen: een fysisch model
"Sam was the first to succeed in creating an artificial cilia surface that is capable of imitating all asymmetric characteristics of biological cilia. In addition to a thorough understanding of microfluidics, this required an enormous creative ingenuity. Sam is a driven person, a modern multidisciplinary engineer with vast social and networking skills."



Martijn Krijnen (TU Delft)

Control System Design for a Contactless Actuation System
"Martijn designed and built a high-tech feedback system for a contactless precision positioning stage for thin substrates. His skills in multi-physics modelling, design of compliant precision stages, magnetic actuators and advanced feedback control systems make him a knowledgeable mechatronic system design engineer. In addition, he is articulate in his writing."

Joep Nijssen
(TU Delft)

A Type Synthesis Approach to Compliant Shell Mechanisms
"Joep has done excellent work in the characterisation of spatially curved elastic elements that can be made using additive metal manufacturing. Using this approach he produced a complex design. Joep is energetic and enthusiastic, and does not shy away from complex theoretical concepts with the accompanying mathematics."

Stefan Gottenbos
(TU Delft)

Follow-The-Leader Control: A mechanical control mechanism for path following deployment of surgical instruments
"Stefan has researched a way to store the shape of a snake-like surgical instrument in a mechanical shape memory register, without the use of (complexity-enhancing) electronics. He was the first to find a way to construct such a shape memory system in a completely mechanical manner. This has ultimately led to a unique prototype that works extremely well."

Pim Duijsens
(TU Eindhoven)

Design of a long stroke actuator unit for the EUV reticle stage
"Pim has shown that he is able to create a mechanical design and analyse its critical points. Although somewhat modest, he had the confidence to know that this was going well, as early as during his initial discussions with ASML. Pim works hard and very autonomously, although he knows how to approach people to act as a sparring partner and to provide relevant input."

Max van Lith
(TU Eindhoven)

Design of a clean z mechanism in the wrist assembly of a wafer handler robot for cluster tools
"Max has covered a design trajectory from concept to elaborated system – this concerns a lifting mechanism, including a voice-coil actuator, for use in a clean vacuum. Max has been outstanding in familiarising himself with statically determined construction, applying elastic hinges and designing motors and magnetic circuits. He works in a systematic and analytical manner."

DSPE KNOWLEDGE DAY: 3D PRINTING IN PRACTICE

On 28 September 2017, a Knowledge Day called '3D Printing in Practice' was organised by DSPE and Fontys Hogescholen at the premises of the Fontys Centre of Expertise HTSM (CoE HTSM) in Eindhoven, the Netherlands. It was an interesting afternoon with presentations by Sjef van Gastel and Rein van der Mast (both Fontys CoE HTSM), Jan Eite Bullema (TNO, AMSYSTEMS Center) and Bart Vanderbeke (Materialise) plus a short hands-on workshop by Martijn Kok (student assistant at Fontys) on the use of the CURA software as a preprocessing data-prep tool for the Ultimaker 3D printer.

From the presentation, workshop (photo on the right) and discussions the participants could not draw any other conclusion than that 3D printing is here to stay and the transition from a prototyping technique to a production technique is happening as we speak. From the presentations we learned for example that every ASML machine currently already contains over forty 3D-printed parts, but also that Adidas will start producing large numbers of '4D shoes'.

3D printing has found its way to education and at the Fontys ObjexLab for example a well-equipped 3D-printing lab has been established. It was initially set up for educational purpose but it also provides consultancy services to SMEs, such as the so-called 'Killer Application Identification' by groups of students under the guidance of Sjef van Gastel, Director Innovative Production Technologies (photo on the next page). Also, in cooperation with Mechatronics Academy and The High Tech Institute,

Participants of the Knowledge Day during the CURA workshop.

a 3-day hands-on short course, 'Design for Additive Manufacturing', has been developed by Van Gastel and Rein van der Mast, Revelator AM Design Paradigm. It combines theory and hands-on practices; the first run will be on 13 to 15 December 2017.

At the Knowledge Day, Van Gastel and Van der Mast gave an overview of the current state of the art including available techniques, advantages & disadvantages plus some killer applications in which the unique properties of 3D-printing reach their full potential. They showed that 3D printing could improve the competitive position of Dutch high-tech industry considerably by adding new functionality to products, like freeform shapes, topology optimisation, mass reduction, and intelligent structures.

Jan Eite Bullema of AMSYSTEMS Center, a joint innovation centre of TNO and the High Tech Systems Center of Eindhoven University of Technology (TU/e HTSC), illustrated the transition by showing striking examples of the benefits of 3D-printed parts ranging from 'personalised human spare parts' to the optimised conventional parts with either improved mass properties for aerospace applications (lighter) or improved thermal behaviour for high-precision equipment.

The audience also learned that cross-disciplinary research at the boundaries of 3D printing and 'deep learning' is also taking place at various institutes and companies. Autodesk for example has high expectations of what they call 'Generative Design'. Their website states: "Generative Design mimics nature's evolutionary approach to design. Designers or engineers input design goals into generative design software, along with parameters such as materials, manufacturing methods, and cost constraints. Then, using cloud computing, the software explores all the possible permutations of a solution, quickly generating design alternatives. It tests and learns from each iteration what works and what doesn't."

Materialise, which employs over 1,500 employees worldwide, offers a range of software solutions, engineering and 3D-printing services. The applications that senior project manager Bart Vanderbeke showed range from prototype car seats and turbine blades with cooling channels to baby-heart artifacts that enable the surgeon to exercise the final operation. Adidas actually is targeting to produce 100.000 pairs of Futurecraft 4D shoes by 2018 and then continue to scale up production into the tens of millions.

Despite the fact that surface finish and dimensional accuracy are topics requiring continued research to stretch the application limits, it is clear that 3D printing has a bright future & present. Completely in line with this observations was the title of Jan Eite Bullema's presentation, "Stop prototyping – start producing". A fitting conclusion for a successful DSPE Knowledge Day.

WWW.FONTYS.NL
WWW.OBJEXLAB.COM
WWW.AMSYSTEMSCENTER.COM
WWW.MATERIALISE.COM
WWW.HIGHTECHINSTITUTE.NL/DFAM
(Design for Additive Manufacturing course)

Sjef van Gastel presenting the current state of the art of 3D printing.

DSPE members with discount to Constructors Day

On 21 November, the Constructeur professional magazine is organising the sixth edition of the Constructors Day at the Evoluon in Eindhoven, the Netherlands. The day is intended for mechanical engineering, designers, research & development teams, consultants, teachers and students (HBO/TU), project engineers and project leaders. The Constructors Day 2017 stands for innovation: "Smart Industry, Internet of Things, Industry 4.0; Or is the constructor smarter?"

DSPE members will receive a discount of 75 euros on the entry fee when signing up for the Constructors Day. See also page 68.

WWW.ENGINEERSONLINE.NL/CONSTRUCTEURSDAG-2017/HOME.HTML

NEWS

Partners for controlled environment

Based on the success of the PP4C concept in the Netherlands, Geerd Jansen, general manager of the Brecon Group, started considering the possibilities of starting up an international version of this strategic alliance. As a former board member of BASF Coatings, he is well aware of the actual priorities of top management. Everywhere in his facilities across multiple countries a CEO likes to see similar, reliable and cost-effective controlled environment areas, having risk management and compliance at the back of his mind – no surprises!

Brecon is therefore now introducing PP4CE: professional partners for controlled environment. Designing, supplying and building turn-key controlled environment areas, such as cleanrooms in the pharmaceutical market, laboratories in the chemical market or high-care areas in the food industry, on a global scale, by the same partner, is new and innovative, according to Jansen.

To roll out the PP4CE concept internationally, Brecon has found an international PP4CE partner in HVAC technology: Stulz from Hamburg, Germany. Other internationally operating PP4CE partners are: Deerns, engineering consultants; Van Aken Concepts, architecture and engineering; AssaAbloy, world leader in entrance systems; BCE, specialised in building CE constructions; Mennen Cleanroom Cranes, lifting technology; and Bolidt, a global leader in artificial flooring technology.

Brecon is now working on a first concept in Leuven, Belgium, creating a cleanroom for cleaning medical devices, together with Stulz Benelux. Working with PP4CE International means, according to Jansen: "A single contact person for all disciplines; excellent price/quality ratio; integration of knowledge from different disciplines; and innovative and sustainable solutions for complex problems.

WWW.BRECON.NL/NEWS/147/PP4CE-ACTIVITIES-STARTED

Newport introduces Non-magnetic UHV Picomotor™ Actuators

Newport, acquired last year by MKS Instruments, has announced the release of the New Focus 83xx-UHV-NM Series of Picomotor actuators with Kapton™ wires. The actuators provide 0.5 inch (12.7 mm) or 1.0 inch (25.4 mm) of travel and are ideal for applications requiring low magnetic susceptibility and permeability such as e-beam lithography, particle acceleration, scientific MRI scanning, Life and Health Sciences and non-magnetic OEM applications.

The new Picomotor actuators can be used in ultra-high-vacuum environments and are perfectly suited for beam steering and other scientific motion control applications in vacuum down to 10^{-9} Torr as well as in radiation applications where Kapton wiring is required. The actuators provide better than 30 nm resolution with minimal backlash, high stiffness and a load capacity of 22 N. Since Picomotor actuators will only move when voltage is applied to the piezo, users can be confident that their set-up will stay put with set-and-forget long-term stability even when the system is powered down.

WWW.NEWPORT.COM/F/VACUUM-PICOMOTOR-ACTUATORS

RGA in a higher gear

Innovar Cleaning Control, based in Eindhoven, the Netherlands, has expanded the capacity of residual gas analysis (RGA). This has been made possible by achieving the accurate prediction of the outcome of measurements after a few hours. The time gain ensures that customers can be served more quickly. That is really necessary, because the demand for RGA measurements is growing enormously. One year ago the waiting time was just one week, now it would be more than two months. "Would...", because Innovar thought it could be faster. As a result, clients have only had to wait four weeks. Hans Cools from Innovar comments: "We have accumulated a lot of data due to our extensive experience. This allows us to predict the outcome after a four-hour measurement, and so we can double the number of measurements." ASML has agreed to this new approach, Cools states. "Other clients know the high demands that ASML imposes on these types of measurements, so they agree as well. They are doing themselves a favour, as they get the results sooner."

WWW.INNOVAR-CC.COM

DSPE members with discount to Constructors Day

On 21 November, the Constructeur professional magazine is organising the sixth edition of the Constructors Day at the Evoluon in Eindhoven, the Netherlands. The day is intended for mechanical engineers, designers, research & development teams, consultants, teachers and students (HBO / TU), project engineers and project leaders. The Constructors Day 2017 stands for innovation: "Smart Industry, Internet of Things, Industry 4.0; Or is the constructor smarter?"

Prof. Mathieu Weggeman, Professor of Organisational Science, especially Innovation Management, at Eindhoven University of Technology, will talk about the practice of innovation. His special focus is on the leading of professionals, strategy formulation, realising collective ambition in teams and organisations, and the next generation's ways of working and values.

Volkert van der Wijk, kinetic artist, Assistant Professor at Delft University of Technology, the Netherlands, and Research Fellow at King's College London, UK, will present his design of a giant piece of kinetic art. The 'Taaie Tiller' (Tough Lifter) is a moving sculpture driven by wind and water power, a machine that encourages the spectator to never give up hope. The design is based on his research on dynamic balancing of parallel manipulators. A 1:6 scale model of the 'Taaie Tiller' has been constructed on the University of Twente campus. The full-scale object will be realised in the port of Rotterdam.

Leon Schipper, founder of the start-up Aryzon from Enschede, the Netherlands, will introduce the very first cardboard Augmented Reality (AR) headset, costing less than 30 euros. The company launched a successful Kickstarter crowdfunding action in May. Because Aryzon's headset is so affordable and works in conjunction with a smartphone, anyone can experiment with AR, including visitors to the Constructors Day, who will all receive one.

The programme lists even more presentations and a mystery guest. The visitors have the chance to win a free Leapfrog 3D printer, and DSPE members will receive a discount of 75 euros on the entry fee when signing up for the Constructors Day.

WWW.ENGINEERSONLINE.NL/CONSTRUCTEURSDAG-2017/HOME.HTML

MI-Partners celebrates ten-year anniversary

In 2007, 'Partners in Mechatronic Innovation' was founded by Leo Sanders. Together with Bart van den Broek, Jan van Eijk and Maarten Steinbuch, he started in the NTS-Group's building in Eindhoven, the Netherlands. In order to deploy his experience as a system architect and department leader for the high-tech industry, he quickly took on his first employees. About 30 colleagues have been added over the past few years.

MI-Partners focuses on the (pre-)development of high-quality mechatronic systems on a project basis. With its knowledge and experience, MI-partners helps customers realise breakthroughs in the design of their systems. During these years, investing in knowledge development, MI-Partners has grown towards the multi-physical mechatronics domain. A world in which vacuum technology, cryogenic environments and thermal conditions play an increasingly important role.

In the coming years, MI-Partners will continue to support its customers with innovative mechatronics solutions. These solutions often give this international customer group a technical edge on the competition. This intensive collaboration with customers will be celebrated in a fun and informal manner with a cosy drink at the end of October. On 15 and 16 November, MI-Partners will be exhibiting at the 2017 Precision Fair in Veldhoven, the Netherlands.

WWW.MI-PARTNERS.NL

The MI-Partners team.

NEWS

59th Ilmenau Scientific Colloquium report

The 59th Ilmenau Scientific Colloquium, themed with "Engineering for a Changing World", took place at the Technische Universität Ilmenau, Germany, on 11-15 September 2017. The title reflected both the breadth and the depth of modern engineering and at the same time the increasing integration of engineering disciplines. In the main topics, many research areas of innovative engineering and adjacent fields were addressed. As always in this conference series, there was a balanced combination of contributions from both academia and industry.

The conference ran in 13 sessions and 4 workshops and reflected the close cooperation of the TU Ilmenau with partners of other universities, scientific institutions and industry. A total of 160 high quality contributions prepared by delegates from 16 countries were reviewed by an international scientific committee and thus formed the backbone for lively discussions. All full papers discussed at the conference will be published permanently under its own URN (universal resource name) at www.db-thueringen.de.

The main conference topics mirrored the research strategy and technological fields established by TU Ilmenau:

- Precision Engineering and Metrology
- Industry 4.0 and Digitalisation in Mechanical Engineering
- Mechatronics, Biomechatronics and Mechanism Technology
- Systems Engineering
- Metallic and Hybrid Materials and Simulation.

Special attention was devoted to the new definition of the international unit of the kilogram and related latest scientific findings in the field of force measurement and weighing technology, as well as to ultra-precise dimensional measurement and nanofabrication, to name just a few topics.

The conference had more than 250 registered participants. A special event was the Tribute Colloquium in memoriam of Prof. Eberhard Kallenbach, who is respected as one of the mentors of mechatronics and mechatronic development methodology. The conference was accompanied by an Academic Gala Concert and an "On the tracks of the Bach family" excursion to the historical town of Arnstadt, which also included a Gala Dinner in a scenic environment.

The 60th Ilmenau Scientific Colloquium will be held in September 2020.

(report by Univ.-Prof. Dr.-Ing. René Theska, Head of Organisation of the Colloquium)

WWW.TU-ILMENAU.DE/IWK

MathWorks Release 2017b strengthens deep learning capabilities

MathWorks recently introduced Release 2017b, which includes new features in MATLAB and Simulink, six new products, and updates and bug fixes. The release also adds new important deep learning capabilities that simplify how engineers, researchers, and other domain experts design, train, and deploy models.

"With the growth of smart devices and the Internet of Things, design teams face the challenge of creating more intelligent products and applications by either developing deep learning skills themselves, or relying on other teams with deep learning expertise who may not understand the application context," said David Rich, MATLAB marketing director at MathWorks.

"With R2017b, engineering and system integration teams can extend the use of MATLAB for deep learning to better maintain control of the entire design process and achieve higher-quality designs faster. They can use pretrained networks, collaborate on code and models, and deploy to GPUs (graphics processing units) and embedded devices. Using MATLAB can improve result quality while reducing model development time by automating ground truth labeling."

WWW.MATHWORKS.COM

Automated precision milling in the medical technology sector

Fetzer Medical, based in Tuttlingen, Germany, employs tailored yet universally flexible Hermle machining centres in its role as an OEM partner manufacturing a wide range of surgical instruments and medical technology components to customer specifications. With the aim of operating exclusively as an independent OEM, establishing all the necessary human and technical resources to that end, Fetzer Medical launched an extensive capital investment, qualification and certification programme, beginning its five-axis machining in 2008.

All relevant materials, including titanium, are machined and Fetzer Medical supplies its customers with ready-to-use products – from prototypes/individual parts to large production runs and complete systems. Roughly 75 percent of the work involves complex milling/drilling operations which have been performed at Fetzer Medical from day one using high-performance five-axis machining centres from Hermle.

Fetzer Medical production manager Bernd Zepf comments on the choice of Hermle machines: "They feature a robust gantry design; the machine concept of three axes in the tool and two axes in the workpiece, which results in optimum tool accuracy, and last but not least excellent accessibility, are ideal for five-axis complete machining in one or two set-ups. Our previous experience helped us to immediately get started with five-axis technology, which we launched in 2008 by acquiring a Hermle C 40 U high-performance five-axis CNC machining centre." Fetzer Medical today runs five machining centres assuring the prompt execution of its OEM production orders.

While the first purchased five-axis C 40 U machining centre was initially used to cement the business' manufacturing expertise and add valuable additional know-how, the machine is now primarily used for pre-fabrication and for machining prototypes, samples and short runs. Additionally, two further C 22 U high-performance five-axis machining centres are equipped with pallet changers/magazines. A further automation level includes a C 12 U high-performance five-axis machining centre combined with an RS 05 robot cell for the production of modularly designed scissors. A C 800 V CNC machining centre was added to provide flexible and universal operation in pre-production, including making reference surfaces and jigs and fixtures.

The working area of a C 22 U high-performance five-axis machining centre featuring the 320 mm diameter NC swivelling rotary table with a multi-clamp system installed on it. (Copyright Hermle)

WWW.HERMLE.DE

Damping simulator motion platforms

E2M Technologies, based in Amsterdam, the Netherlands, produces durable electric linear and rotary actuator solutions, as well as multi-DoF electric motion systems. The Dutch company specialises in subsystems for simulators for a wide range of applications. Depending on whether aircraft cockpits, passenger cars, offshore wave compensation or product testing are simulated for industrial applications or the effects of entertainment rides need to be tested in an electric motion system, the parameters in terms of size, weight and speed vary. However, the principle of movement always remains the same.

Nevertheless, simulator construction is very complex. This is because there are usually simultaneous movements in the X, Y and Z axes. Due to different loads, E2M was aware in the planning phase that they would need dampers with different characteristics. ACE Stoßdämpfer, with headquarters in Langenfeld, Germany, offers a variety of universal damping solutions which convert kinetic energy into heat.

ACE recommended profile dampers and safety bumpers to E2M. Both product families belong to the TUBUS line offered by ACE and are perfect alternatives to industrial shock absorbers when masses don't need to be decelerated to an exact point. Comprising seven designs, engineers have around 150 individual products to choose from when opting for ACE's TUBUS for a wide range of their applications. With the compact, high-performing and durable machine elements it is possible

■ ACE's TUBUS TA dampers (see inset) attached to an E2M motion system.

to produce degressive, progressive or approximately linear characteristics.

In this case, profile dampers and safety bumpers absorb drive forces of up to 200 kN. For E2M the electric motion technology profile dampers from the TUBUS TA family were selected, which is mainly used for its degressive characteristics on the one hand. Moreover, the so-called TC-series from ACE's line of safety bumpers plays an important role in securing the construction of E2M's durable electric linear and rotary actuator solutions on the other hand. These maintenance-free, ready-to-install damping elements made of co-polyester elastomer have been specially developed for use in crane systems. Their characteristics make them ideal for capturing the sometimes extremely high forces at the electric motion platforms for simulators.

WWW.ACE-ACE.DE

WWW.E2MTECHNOLOGIES.EU

NEWS

Investing in ultrafast High-Throughput Atomic Force Microscopy

Last month, it was announced that Nearfield Instruments of Delft, the Netherlands, has found two investors, enabling Nearfield Instruments to start the development of its first ultrafast High-Throughput Atomic Force Microscopy (HT-AFM) system for metrology of advanced ICs. Samsung Venture Investment Corporation and Innovation Industries, a Dutch investment fund for high-tech innovations in the Netherlands, together invest 10 million euros. Nearfield Instruments is a spin-off of the Netherlands Organisation for applied scientific Research TNO. TNO will remain a shareholder in Nearfield Instruments.

To achieve new functionalities, and to make optimum use of the available wafer space, IC devices will shrink to atomic dimensions using novel, sensitive materials and newly designed fully three-dimensional configurations. In order to accommodate these trends in a technologically and economically viable way, breakthroughs in metrology processes and equipment for IC device development and manufacturing are required. Without it, Moore's Law would come to an end.

Atomic Force Microscopy (AFM) is a well-known technology for imaging the smallest features and is often applied in research. An AFM system uses an atomically-sharp probe to scan (but just not touch) the surface of the sample under investigation to sense the pattern on it. However, AFM was always considered too slow for industrial applications. Five years ago, TNO initiated the NOMI (Nano Opto-Mechatronics Instrumentation) programme, which combines scientific research with application know-how, leading to multiple improvements with the potential to make AFM up to 1,000 times faster than traditional AFM technology. This makes Nearfield Instruments' AFM solution of prime interest for the semiconductor industry.

Dr. Hamed Sadeghian, principal scientist at TNO and scientific leader of NOMI: "This patented revolutionary architecture is based on parallelising AFM. The parallelisation is achieved by miniaturising the AFM and operating many of them simultaneously. This instrument has the advantage that each miniaturised AFM can be operated independently, which allows one to measure several physical parameters simultaneously; while one mini AFM measures nanoscale topography, another instrument can measure mechanical, electrical, or thermal properties, making it a lab-on-an-instrument. The key to this was to miniaturise AFM to the size of a matchbox to achieve very high measurement bandwidth combined with very high stability of nanoimaging by shortening the metrology loop.

To accelerate market introduction of this High-Throughput AFM, TNO launched the spin-off company Nearfield Instruments in 2016. Within the next few years, Nearfield Instruments will develop HT-AFM to a viable product for the semiconductor market. CEO of Nearfield Instruments Dr. Roland van Vliet comments: "The support and commitment of our new partners Samsung Venture Investment Corporation and Innovation Industries provides us all at Nearfield Instruments with the right expertise and momentum to realise atom-scale metrology at industry-level throughput. Together we'll enable the semiconductor industry in its continuous endeavour towards even more powerful and energy-efficient electronics."

WWW.NEARFIELDINSTRUMENTS.COM

Nearfield Instruments' solution for making IC inspection up to 1,000 times faster is AFM parallelisation, achieved by miniaturising the AFM and operating many of them simultaneously.

Swiss-Delft watch collaboration

Modern mechanical watches are still operating on the so-called 'balance and hairspring' principle, a time-keeping device that was invented by Dutch scientist Christiaan Huygens in 1675. The LVMH Watch Division and its R&D Science Institute, Delft University of Technology and TU Delft spin-off Flexous joined forces to develop a completely new regulator technology. The technique is now brought to the market with the ZENITH Defy Lab watch.

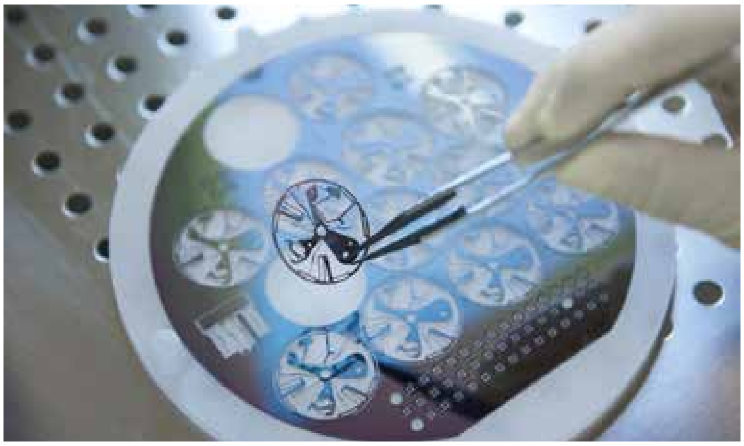
"This is the first time since 1675, when Huygens invented the pendulum clock, that there is a new technology in regulators. The new regulator has no hairspring, no balance wheel and doesn't need oil, because it has no friction. Accurate to one second in 24 hours, it generates the most accurate mechanical watch ever", says Guy Sémon, CEO of the R&D Science Institute of the LVMH group.

A regulator traditionally has numerous parts and is composed of multiple layers. TU Delft and its spin-off Flexous, in a close collaboration with the R&D Institute of the LVMH Watch Division, developed a 'monolithic' regulator, made in a single layer and out of one piece, so it doesn't need assembly. The regulator is made of silicon-based materials and operates at a high frequency (15 Hz). Since it is one piece, there is no friction, which extends the power reserve to at least 60 hours. The regulator maintains a very accurate frequency, all the way from when it is fully wound to when the power reserve is almost empty.

"What makes this project particularly innovative, is the collaborating consortium of partners", says Nima Tolou, co-founder of Flexous. R&D from LVMH Watch Division played a key role by sharing their know-how and facilities on mechanical watch design. The TU Delft provided the knowledge with a leading group in fundamental research on compliant mechanisms and Flexous is the ambitious start-up that took off from the research, focusing on engineering of flexure-based mechanisms.

Not only the use of compliant mechanisms in the most intricate part of a mechanical watch was explored, but the whole system was considered, where all functions were redefined at a high abstract level to find new possibilities. Traditionally, the escapement mechanism consists of a regulator, a distributor, an escapement wheel and many other tiny parts such as axes and stones. All of this is now combined in one part, which does the delicate task of time keeping.

The new watch was launched at a press conference on 14 September 2017 at Manufacture Zenith in Le Locle, Switzerland. TU Delft Professor Just Herder, promotor of the Ph.D. students in the project, was a keynote speaker.



The 'monolithic' regulator was developed by LVMH Watch Division and its R&D Science Institute, Delft University of Technology and TU Delft spin-off Flexous.

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Brecon Group can attribute a large proportion of its fame as a cleanroom builder to continuity in the delivery of quality products within the semiconductor industry, with ASML as the most important associate in the past decades.

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The LiS is a modern level 4 MBO school, with a long history (founded in 1901). The school encourages establishing projects in close cooperation with industry and scientific institutes, allowing for high level "real life" work. Under the name LiS-Engineering and LiS-Academy the school accepts contract work and organizes education for others.

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